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PATENT
Attorney Docket No. MLB-038

#44

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

APPELLANTS:	Christopher Turner et al.		
SERIAL NO.:	08/820,057	GROUP NO.:	2673
FILING DATE:	March 18, 1997	EXAMINER:	David Lee Lewis
TITLE:	PRINTABLE ELECTRONIC DISPLAY		

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SUPPLEMENTAL BRIEF ON APPEAL UNDER 37 C.F.R. § 1.193(b)(2)

This is a Supplemental Appeal Brief in support of Appellants' Request for Reinstatement of the Appeal Under 37 C.F.R. § 1.193(b)(2) ("the Request for Reinstatement") filed concurrently herewith. A Notice of Appeal for this application was filed on September 14, 2001, and an Appeal Brief was filed on November 14, 2001. Additionally, a Reply Brief with a Corrected Appeal Brief was filed on February 14, 2002 in response to the Examiner's Answer mailed on December 18, 2001.

The Request for Reinstatement is filed in response to the Office Communication mailed from the U.S. Patent and Trademark Office on October 30, 2003 ("the Post-Appeal Communication"), reopening prosecution of this application after consideration of Appellants' Appeal Brief and prior art submission.

The Commissioner is hereby authorized to charge any additional fees that may be due, for further extensions of time or any other purpose associated with this submission, or credit any overpayment, to Appellants' undersigned counsel's deposit account number 20-0531 with reference to docket number MLB-038.

REAL PARTY IN INTEREST

The real party in interest is the Massachusetts Institute of Technology, the owner of the present application.

RELATED APPEALS AND INTERFERENCES

The Appellants and the Appellants' legal representative are unaware of any other appeals or interferences that will directly affect or be directly affected by or have a bearing on the Board's decision in the pending appeal.

STATUS OF CLAIMS

The application as filed contained 45 claims, which were made subject to a restriction requirement. Applicants elected claims 1-34 for prosecution, and subsequently canceled claim 29 in the amendment filed on February 15, 2000. Accordingly, claims 1-28 and 30-34 remain pending and subject to the present appeal. The claims on appeal appear in the Appendix attached hereto.

STATUS OF AMENDMENTS

No amendments have been filed subsequent to the Office action mailed on June 15, 2001.

SUMMARY OF INVENTION

The present invention involves electronically addressable displays that may be fabricated using printing techniques.[1] In particular, printing processes can be used to deposit the electrodes, insulating material, the display itself, and an array of nonlinear devices to facilitate addressing.[2] Accordingly, fabrication of the displays of the present invention may be accomplished at significantly lower cost and with far less complexity than would obtain using other fabrication technologies.

As set forth in the claims, a display in accordance with the present invention comprises a first set of display electrodes associated with a first layer; a second set of display electrodes associated with a second layer distinct from the first layer and disposed in an intersecting pattern with respect to the first set of electrodes, the first and second sets of electrodes not contacting one another; a particle-based, nonemissive display; and a plurality of nonlinear elements.[3]

The display and the nonlinear elements are sandwiched between the first and second display electrode layers so as to electrically couple at least some electrodes of the first layer with corresponding electrodes of the second layer at regions of intersection. This facilitates actuation of the display by the electrodes at the regions of intersection.

Accordingly, the present claims recite a structure (seen in truncated end view) as follows:

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[1] Specification at page 5, lines 6-7.

Display Electrode

Display

Nonlinear Element

Display Electrode

The purpose of this construction is to allow the nonlinear element to govern switching of the display. Unless both intersecting electrodes sandwiching a display element are energized, the voltage across the nonlinear element will not exceed the element's threshold, so very little current will flow between the electrodes; as a result, the display will not be activated inappropriately. It is for this reason that the claims require the display and nonlinear elements to *electrically couple* the electrodes—i.e., they are *in series*.[4]

ISSUES

The issue on appeal is whether claims 1-28 and 30-34 are patentable under 35 U.S.C. §103(a) over article by Chiang et al. entitled, "A High Speed Electrophoretic Matrix Display" ("Chiang") in view of U.S. Patent No. 5,220,316 to Kazan ("Kazan"); U.S. Patent No. 5,216,530 to Pearlman et al. ("Pearlman"); and Japanese Patent No. 64-86226 to Inoue et al. ("Inoue").

[2] See FIGS. 1, 4A-4D.
[3] See, e.g., FIG. 4B.
[4] Specification at page 12, lines 4-5.

GROUPING OF CLAIMS

Appellants believe that the claims stand or fall together.

ARGUMENT

As a preliminary matter, Appellants note that the Examiner reopened prosecution in light of the "Applicant's persuasive arguments in the Appeal Brief filed on 7/25/2003."[5] This statement and the remainder of the Post-Appeal Communication indicates that the Examiner finds our prior arguments persuasive, but ultimately mooted given Chiang[6] and the alleged printing features of Kazan, Pearlman, and Inoue. Appellants respectfully submit that Chiang does not teach or suggest the structure recited in claims 1-28 and 30-34, and therefore request reinstatement of the appeal and consideration of the arguments presented below. In addition, Appellants refer to the arguments made with regard to Kazan[7] and the other secondary references in the Appeal and Reply Briefs filed respectively on November 14, 2001 and February 14, 2002.

I. Claims 1-28 and 30-34 constitute non-obvious subject matter and are patentable over Chiang in view of Kazan, Inoue, and Pearlman.

As explained above, the present claims require the display and nonlinear elements to be *sandwiched between* the first and second electrode layers. Moreover, the first and second electrode layers form an intersecting pattern, and the sandwiched display and nonlinear elements must *electrically couple* electrodes of the first and second layers where they *intersect.*

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[5] Post-Appeal Communication mailed October 30, 2003 at 2. Appellants assume that the Examiner actually is referring to the Reply Brief filed with a Corrected Appeal Brief on February 14, 2002 as no Appeal Brief was filed on July 25, 2003.

[6] Appellants include a clean copy of the Chiang reference that was obtained after receipt of the Post-Appeal Communication as Exhibit A. The improved quality of this copy facilitates evaluation of the actual structure disclosed by Chiang.

[7] The Examiner expressly concedes that "Kazan does not teach ... the display and the nonlinear elements being sandwiched between the first and second electrode layers so as to electrically couple at least some of the electrodes of the first layer with

Additionally, the claims require that *actuation of the display* occurs at *the regions of intersection*. These features are nowhere disclosed or suggested in the cited art.

A. The *Chiang* Reference

Chiang does not show a nonlinear device sandwiched between *two* display electrodes disposed in an *intersecting* pattern as required by the present claims. Instead, the relevant portions of Chiang's semiconductor structure include a complex arrangement requiring *four* electrodes. In particular, Chiang teaches one type of column electrode and three types of row electrodes (capacitor, pixel, and transparent), but does not provide a detailed description as to how they all are interconnected and addressed. Nonetheless, what is clear in Figure 1 of Chiang is that the placement of the varistor material occurs *below* the display. Specifically, the varistor is disposed between the *column* electrode and the capacitor *row* electrode. Therefore Chiang's regions of intersecting row and column electrodes *cannot sandwich* the display material as claimed because the display material is positioned *above* these regions of intersection. The *nonlinear device* is sandwiched between display electrodes but the display *is <u>outside</u> the sandwich*. Further, any possible regions of intersection between the column electrode and the pixel row electrodes are likewise disposed below the display and incapable of *sandwiching* the display material as claimed.

Moreover, Figure 1 reveals that any electrical coupling that occurs at points of electrode intersection must be between the capacitor row electrode and the column electrode, which do not sandwich the display material. Chiang's discussion relating to the charging of the storage capacitors through the varistor layer in combination with the positioning of the layers in Figure 1

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corresponding electrodes of the second layer at regions of intersection." *See* Office Action mailed on June 15, 2001 (hereafter the "6/15/01 Office Action") at 3.

supports this interpretation.[8] Consequently, the topmost transparent row electrode and the column electrode are not electrically coupled at regions of intersection. This follows because any interaction between the bottom column electrode and the top transparent row electrode must occur indirectly, i.e., by way of the capacitor row electrode and the pixel electrode. Thus the nonlinear device (varistor) does not electrically couple the display electrodes nor are the transparent electrode and column electrode electrically coupled, as required by the present claims.

Furthermore, the present claims require that "actuation of the display by the electrodes" occur "at said regions" of intersection. Actuation in Chiang occurs *beneath the display material* through the interaction of the pixel, capacitor, and column electrodes. Consequently, the actuation approach claimed by the Appellants is not met by Chiang.

B. The Secondary References

The Post-Appeal Communication concedes that "Chiang et al. lacks said printing technique as claimed"[9]; Chiang is cited solely for its alleged structure. To cure this deficiency, the Examiner cites "the printing technique which is provided by Kazan, Pearlman, and Inoue."[10] Whatever these references disclose in terms of printing, certainly they do not provide the sandwich structure that Chiang lacks. The Examiner does not contend otherwise. Therefore, Appellants submit that claims 1-28 and 30-34 are novel and non-obvious at least because none of the cited references, alone or in combination teaches all of the limitations set forth in the claims.

[8] Chiang at page 114, paragraph 2.
[9] Post-Appeal Communication mailed October 30, 2003 at 4.
[10] Id. at 2.

CONCLUSION

For all of the foregoing reasons we submit that the Examiner's rejections of claims 1-28 and 30-34 were erroneous, and reversal thereof is respectfully requested.

Respectfully submitted,

Date: January 30, 2004

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APPENDIX

1. A printable electronic display comprising:

a. a first set of display electrodes associated with a first layer;

b. a second set of display electrodes associated with a second layer distinct from the first layer and disposed in an intersecting pattern with respect to the first set of electrodes, the first and second sets of electrodes not contacting one another;

c. a particle-based, nonemissive display; and

d. a plurality of nonlinear elements,

the display and the nonlinear elements being sandwiched between the first and second display electrode layers so as to electrically couple at least some electrodes of the first layer with corresponding electrodes of the second layer at regions of intersection and thereby facilitate actuation of the display by the electrodes at said regions.

2. The display system of claim 1 wherein the nonemissive display is an electrophoretic display.

3. The display system of claim 1 wherein the nonemissive display is a rotating-ball display.

4. The display system of claim 1 wherein the nonemissive display is an electrostatic display.

5. The display system of claim 1 further comprising a thin, flexible substrate.

6. The display system of claim 1 wherein the first and second sets of electrodes are each arranged in a planar configuration, the electrodes of the first set being orthogonal to the electrodes of the second set.

7. The display system of claim 6 wherein the electrophoretic display material and the nonlinear elements are arranged in planar form and sandwiched between the first and second sets of electrodes.

8. The display system of claim 1 wherein the electrophoretic display comprises a plurality of discrete, microencapsulated electrophoretic display elements.

9. The display system of claim 8 wherein the electrophoretic display comprises:

a. an arrangement of discrete microscopic containers, each container being no longer than 500 μm along any dimension thereof; and

b. within each container, a dielectric fluid and a suspension therein of particles exhibiting surface charges, the fluid and the particles contrasting visually, the particles migrating toward one of the sets of electrodes in response to a potential difference therebetween.

10. The display system of claim 1 wherein the first and second sets of electrodes are printable, at least one of the sets of electrodes being visually transparent.

11. The display system of claim 1 wherein the nonlinear elements are printable.

12. The display system of claim 1 wherein the electrophoretic display is printable.

13. The display system of claim 11 wherein the nonlinear elements are a print-deposited ink exhibiting a nonlinear electrical characteristic.

14. The display system of claim 13 wherein the ink comprises:

a. a binder for printing; and

b. ZnO particles doped with at least one compound selected from the group consisting of sintered ZnO, Sb_2O_3, MnO, MnO_2, Co_2O_3, CoO, Bi_2O_3 and Cr_2O_3.

15. The display system of claim 14 wherein the binder comprises ethyl cellulose and butyl carbitol.

16. The display system of claim 15 wherein the binder further comprises a glass frit.

17. The display system of claim 15 wherein the binder comprises an epoxy resin.

18. The display system of claim 15 wherein the binder comprises a photohardenable resin.

19. The display system of claim 13 wherein the ink comprises:

a. a binder for printing; and

b. a doped, particulate silicon.

20. The display system of claim 19 wherein the binder comprises ethyl cellulose and butyl carbitol.

21. The display system of claim 19 wherein the binder further comprises a glass frit.

22. The display system of claim 19 wherein the binder comprises an epoxy resin.

23. The display system of claim 19 wherein the binder comprises a photohardenable resin.

24. The display system of claim 1 wherein the electrodes comprise a print-deposited conductive ink.

25. The display system of claim 19 wherein the electrodes comprise a print-deposited conductive ink providing a rectifying contact to the silicon.

26. The display system of claim 24 wherein the ink is transparent.

27. The display system of claim 24 wherein the ink comprises indium tin oxide.

28. The display system of claim 1 wherein each set of electrodes is arranged in lanes with spaces therebetween, and further comprising an insulating material located in the spaces.

29. (Canceled)

30. The display system of claim 1 wherein the nonlinear elements comprise Schottky diodes.

31. The display system of claim 1 wherein the nonlinear elements comprise PN diodes.

32. The display system of claim 1 wherein the nonlinear elements comprise varistors.

33. The display system of claim 1 wherein the nonlinear elements comprise silicon films formed from silicide salt.

34. The display system of claim 1 wherein the nonlinear elements comprise a polymer conductor.

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11.5/4:10 P.M.: A High Speed Electrophoretic Matrix Display

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Introduction

The electrophoretic (EP) display is a passive device noted for its high contrast, wide viewing angle, non-volatile storage and low power consumption.[1] However, due to its lack of well-defined thresholds, an active matrix is often necessary to control individual pixels in a large information content display. The use of such active matrices as thin film transistor arrays[2] and silicon transistor arrays[3] has long been considered but not realized. Since 1978, Castleberry has reported a much simpler approach for the active matrix [4,5] which is also applicable to the EP medium. The metal oxide varistor controlled liquid crystal display was built by applying only appropriate electrode and insulator patterns to a wafer of the varistor and using it as the rear cell wall. We will report here the first application of the varistor driving scheme to a high speed EP matrix display.

Design Considerations

Figure 1 shows one of the structures used in a varistor-capacitor array driven electrophoretic (VCEP) device. The symmetrical breakdown voltage threshold of the varistor allows for matrix addressing by a 2V/1V or 3V/1V scheme in either image sense. The local storage capacitors will facilitate much shorter address time than the natural response time of the EP medium.

In designing the VCEP device for operation with the 2V/1V scheme, the following conditions must be met:

1. The half select voltage, V_h, must be lower than the varistor breakdown voltage, V_b.
2. The capacitance of the storage capacitor, C_s, should be much larger than that for the varistor, C_v.
3. The net voltage drop across a fully selected EP pixel, $2V_h$-V_b, should be high enough to give reasonable response time. This is about 50 volts.
4. The charge stored in the capacitor, $C_s(2V_h$-$V_b)$, must be large enough to transport all the particles across the EP layer. This is about 100 nC/cm^2.
5. The RC time for charging C_s through the varistor in the on-state must be shorter than the the address time.
6. The RC time for C_s to leak through the varistor in the off-state must be longer than the natural response time of the EP medium, i.e., 20 ms.

Device Construction

According to the considerations above, the present VCEP device is built on a 17 mil wafer cut from a 2 in. diameter commercial varistor device. The 31 l/in. 1 $in.^2$ active area contains a 32x32 matrix or 1024 pixels. The insulators are dry film photoresists and Al is used in all electrodes. The capacitors are formed by fabricating a second set of row electrodes under each row of pixel electrodes and separating them by a layer of dielectrics using Al_2O_3, Ta_2O_5 or photoresists. The 2 mil thick EP layer consists of a dispersion of positively charged TiO_2 white particles in a blue dielectric fluid.

The yield in a given VCEP device has been consistently above 90%. In a random check of the V-I characteristics of the varistor elements on a wafer, the breakdown voltage varied by 5 volts out of 70 volts.

Device Operation

Figure 2 shows several graphical and alphanumeric images on the VCEP device in actual size. These were written row-at-a-time by applying 20μs , $\pm$70 volt pulses to the selected row and column electrodes. A 1000 line display would require a 20 ms frame time or be driven at 50 frames/sec. This amounts to a 0.1% duty factor. Since the EP medium exhibits memory, no refreshing is necessary. Power consumption can be further reduced.

Conclusion

We have demonstrated a high speed electrophoretic matrix display which retains its attractive image qualities at the achieved resolution. Although the varistor controlling technique can be theoretically scaled to larger areas and higher resolution, the availability of such EP displays depends on the availability of varistors of finer grain size and larger area.

Acknowledgement

The authors would like to thank Mark Zarzycki and Doug Bailey for their skillful assistance.

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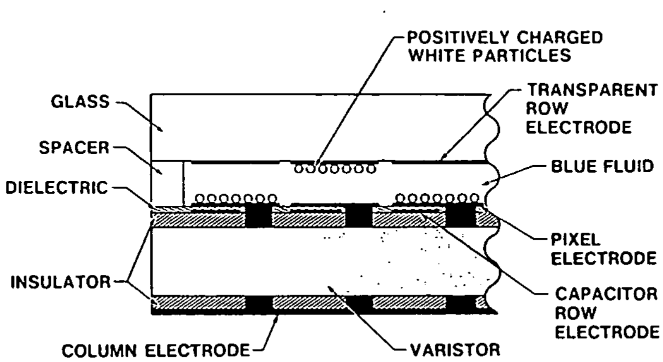

Figure 1 VCEP Device Structure

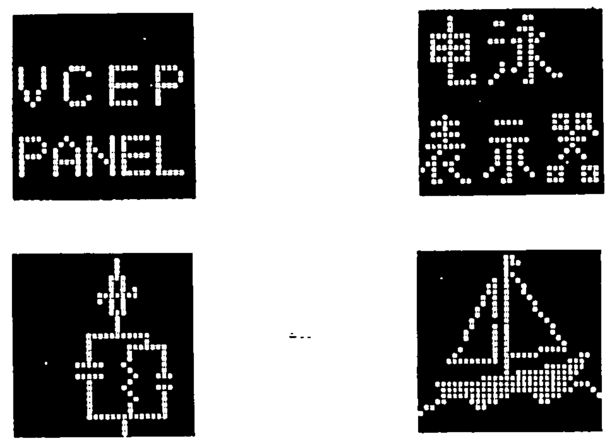

Figure 2 Images Written Row-at-a-time with ±70 V, 20 μs pulses.

US005220316A

United States Patent [19]
Kazan

[11] Patent Number: 5,220,316
[45] Date of Patent: Jun. 15, 1993

[54] NONLINEAR RESISTOR CONTROL CIRCUIT AND USE IN LIQUID CRYSTAL DISPLAYS

[76] Inventor: Benjamin Kazan, 557 Tyndall St., Los Altos, Calif. 94022

[21] Appl. No.: 758,522

[22] Filed: Sep. 6, 1991

Related U.S. Application Data

[63] Continuation of Ser. No. 375,133, Jul. 3, 1989, abandoned.

[51] Int. Cl.[5] G09B 3/36
[52] U.S. Cl. 340/784; 340/719; 359/57
[58] Field of Search 340/784, 719, 765; 359/58, 55, 36, 57; 428/329; 338/20, 21; 264/56

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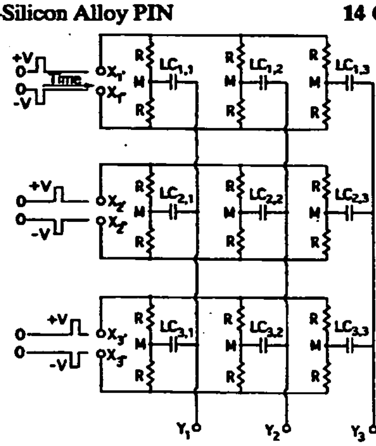
Primary Examiner—Ulysses Weldon
Assistant Examiner—Doon Yue Chow
Attorney, Agent, or Firm—W. Douglas Carothers, Jr.

[57] ABSTRACT

A control circuit comprises a combination of two or more nonlinear resistor elements having a common electrical junction and a nonlinear current/voltage characteristic, the impedance at the common electrical junction being controlled in accordance with switching voltages applied to the nonlinear resistor elements. These nonlinear resistor elements may be connected to one terminal of a load element, such as a liquid crystal element or a printing element. An array of such load elements, such as printing elements or liquid crystal elements of the microencapsulated type, combined with these nonlinear resistor elements form, respectively, a printing engine or display device. The nonlinear resistor elements are composed of semiconducting or conducting powder particles bonded together with an insulating or semiconducting binder.

14 Claims, 2 Drawing Sheets



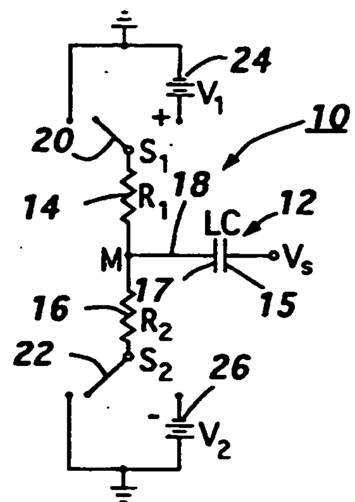

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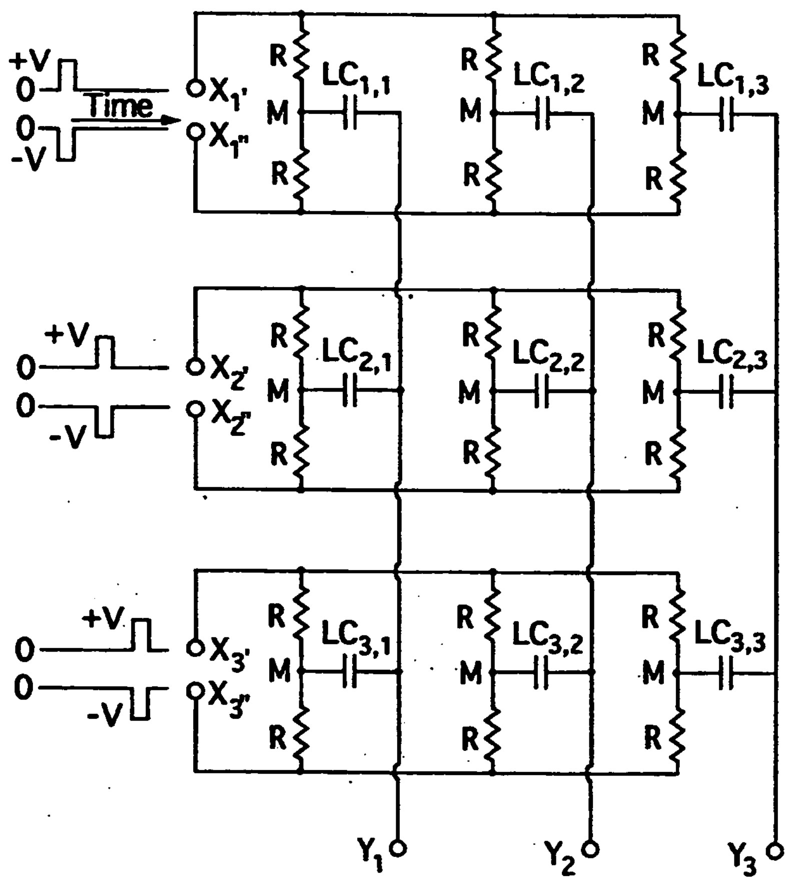
FIG. 1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Y_3

FIG. 3

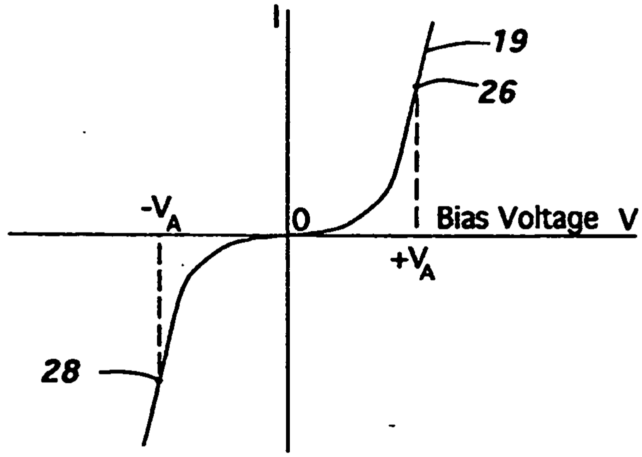
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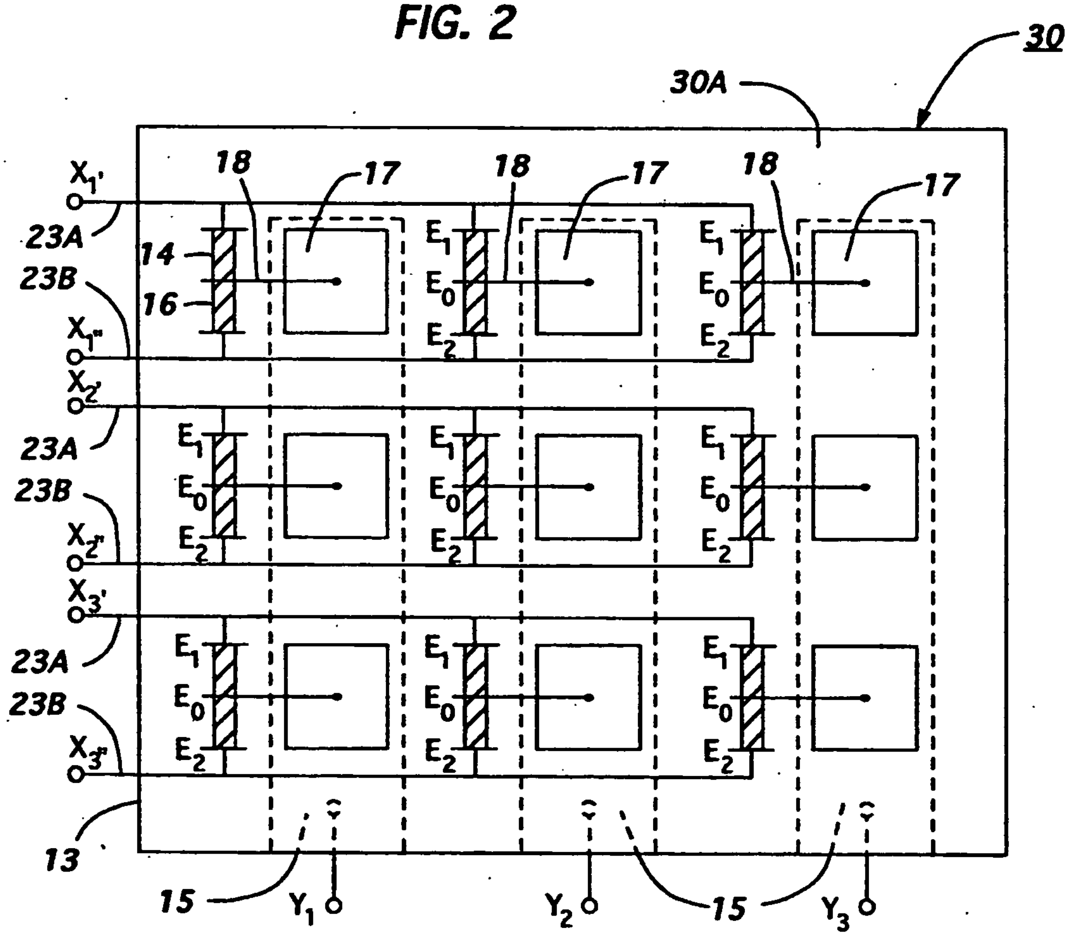
FIG. 2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E_1
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X_2'
23A
23B
X_2''
X_3'
23A
23B
X_3''
13
15
Y_1
Y_2
15
Y_3

FIG. 4

NONLINEAR RESISTOR CONTROL CIRCUIT AND USE IN LIQUID CRYSTAL DISPLAYS

This is a continuation of copending application Ser. No. 07/375,133 filed Jul. 3, 1989, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to switching circuits and in particular to nonlinear resistor control circuits and their applicability to devices for display or printing.

Of the various forms of flat-panel displays being developed for television and other electronic applications, those making use of liquid crystal technology constitute one of the most important types. Much of the interest in such displays derives from their low voltage, low current requirements as well as their low cost and relatively long operating life. In their simplest form, such displays consist of a matrix of twisted nematic liquid crystal elements addressed by means of voltages applied to them by a set of X and Y electrodes. As is well known in the art, however, while such displays can produce satisfactory images when the number of rows of picture elements is limited, their contrast and viewing angle becomes progressively smaller as the number of rows of picture elements is increased. In practice, satisfactory display panels of this type can be made which contain less than about 100 to 200 rows of elements. Although the number of rows can be somewhat increased by using some of the newer forms of liquid crystals materials, such as, the "super-twisted" and ferroelectric types, the long response time of the former and the absence of gray scale of the latter make these alternative approaches unsuitable for television and other applications where images involving motion and containing gray scale are required.

To overcome the limitations of X-Y addressed twisted-nematic displays and allow their use in high-resolution or high-definition-television (HDTV) displays containing a large number of rows of picture elements, a variety of "active matrix" schemes have been developed in which one or more, semiconductor elements are provided for each liquid crystal element. In all these schemes, the semiconductor elements serve to more efficiently block the addressing signals from reaching unselected liquid crystal elements during the line-by-line addressing cycle. In addition, they prevent the capacitive electric charges established across the liquid crystal elements by the signal voltages during addressing from rapidly leaking off the elements between successive addressing cycles, thus increasing the amount of light modulation produced.

The semiconductor elements used for this purpose are generally in the form of field-effect transistors or diodes. These are fabricated from a material such as silicon in amorphous or polycrystalline form to enable the deposition of multi-element arrays at relatively low temperature on a large area substrate. Although displays making use of field effect transistors have received the most attention until now, various factors make this approach difficult. Among these are obtaining a high yield of transistors with the desired electrical characteristics, instability and drift of the transistor characteristics with time, and short circuits occurring at the many crossover points of the conducting lines required for such large arrays of transistor and liquid crystal elements. Since many of these problems are reduced or eliminated when two terminal semiconductor elements are employed, there has been a growing interest in the use of such semiconductor elements in place of the three terminal transistor elements.

Of the various active matrix display devices which incorporate two terminal semiconductor elements, several make use of one or more rectifying diode elements at each liquid crystal element. In one arrangement, as described, for example, in the paper "A Novel Back-to-Back Diode Element for Addressing LCDs" by T. Sato et al., in the 1987 *Digest of the Society for Information Display*, pp. 59–61, a pair of back-to-back rectifying diodes is connected in series with each liquid crystal element. In another arrangement, a pair of parallel diodes of opposite polarity is connected in series with each liquid crystal element as described in the paper, "An LC-TV Display Controlled by a-Si Diode Rings" by S. Togashi et al., in the *Proceedings of the SID*, Vol. 26(1), pp. 9–15, 1985. In a third arrangement, two diodes of the same polarity are connected in series with each other, with the junction of these diodes connected to the liquid crystal element, as described in the paper, "A New Amorphous-Silcon Alloy PIN Liquid Crystal Display" by Z. Yaniv et al. in the 1986 *Digest of the Society for Information Display*, pp. 278–280. In place of rectifying elements, other schemes have also been explored in which an electrically-symmetrical nonlinear resistive element is connected in series with each liquid crystal element. An example of such a scheme is described in the paper, "The Optimization of Metal-Insulator-Metal Nonlinear devices for Use in Multiplexed Liquid Crystal Displays" by D. R. Baraff et al. in the *IEEE Transactions on Electron Devices*, Vol. ED-28, pp. 736–739, 1981.

In all of the above schemes, the fabrication of a large area display, for example, 12"×12" is size or larger, poses several special problems. Aside from the increasing difficulty of avoiding defective circuit elements as the number of picture elements is increased, the costs of panel fabrication are greatly increased since fabrication of the required diode semiconductor elements requires the use of vacuum systems specially designed for processing such large substrates. In addition, since the glass plates confining the liquid crystal layer must be maintained at a uniform spacing, for example, 5 μm over the entire area, further fabrication problems are encountered.

It is an object of this invention to simplify the basic structure of a display panel or printing array to lower the cost of fabrication and reduce the possibility of defects in a multi-element large area device. Another object of this invention is to enable the fabrication of the semiconductor circuit elements of an image generating device in a normal room environment, thus avoiding the need for processing the device in a vacuum system. Still another object of this invention is to enable the fabrication of a display device on a thin layer of plastic material in which tiny liquid crystal cells are encapsulated, thus avoiding the difficulties of providing conventional liquid crystal layers with uniform thickness over a large area.

SUMMARY OF THE INVENTION

According to this invention, a control circuit comprises a combination of two or more nonlinear resistor elements having a common electrical junction and a nonlinear current/voltage characteristic, the impedance at the common electrical junction being controlled in accordance with bias voltages applied to the nonlinear

resistor elements. These nonlinear resistor elements may be connected to one terminal of a load element, such as a liquid crystal element or a printing element or a display element or the like. An array of such load elements, such as printing elements or liquid crystal elements of the micro-encapsulated type, combined with these nonlinear resistor elements form, respectively, a printing engine or display device. The nonlinear resistor elements are composed of semiconducting or conducting powder particles bonded together with an insulating or semiconducting binder.

Other objects and attainments together with a fuller understanding of the invention will become apparent and appreciated by referring to the following description and claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit arrangement comprising two nonlinear resistor elements coupled to a single load element.

FIG. 2 is a graphic illustration of the nonlinear current/voltage characteristic of the nonlinear resistor elements.

FIG. 3 is an electrical schematic diagram of a nine-element display or printing device comprising this invention.

FIG. 4 is a plan view of a nine-element display or printing device comprising this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows the circuit arrangement 10 of a single element of an image generating device designed in accordance with the present invention. As indicated, a signal voltage, V_s, is applied to one terminal of a load element 12, such as a liquid crystal element or a printing element or a display element or the like. For purposes of explanation of the invention, reference will be made to load element 12 as a liquid crystal element (LC) element, although this element may also be a printing element in a marking engine or other type of energizable display element. The other terminal of load element 12 is connected to the junction M of nonlinear resistor elements R_1 and R_2 at 14 and 16 via conductor 18. Each of these resistors 14 and 16 has a superlinear current-/voltage characteristic, such as illustrated in FIG. 2, whereby the current increases, for example, as the fifth or higher power of the applied bias voltage. As shown in FIG. 2, depending on the bias voltage maintained across such a resistor, its incremental resistance can be greatly varied. For example, at a bias voltage close to point 0, the slope of the curve is very low, making the incremental resistance very high, while at bias voltages $+V_A$ or $-V_A$, the slope of the curve is high, making the incremental resistance very low.

With switches S_1 and S_2 of FIG. 1 at 20 and 22, both held in position 1, essentially no voltage is applied across resistors 14 and 16. Since their incremental impedance is very high, the signal voltage, V_s is prevented from charging LC element 12. However, if both switches 20 and 22 are shifted to position 2, the relatively large voltage difference, i.e., V_1+V_2, due to coupling to sources 24 and 26, applied across resistors 14 and 16 results in a substantial current flow through them causing the junction M to have a very low incremental resistance. Assuming that the ratio of the voltages V_1 and V_2 is properly chosen, point M will also remain at zero potential with a very low impedance to ground. The signal voltage, V_s, will now cause a current to flow through the LC element 12, building up a charge across it in accordance with the magnitude of V_s, and resulting in a corresponding change in its light transmission.

FIG. 3 illustrates the circuit arrangement of a multi-element display device consisting of picture elements comprising the combination of LC element 12 and nonlinear resistor elements 14 and 16 of FIG. 1. It should be noted that in FIG. 3, to simplify the switching circuit, the two nonlinear resistors 14 and 16 associated with each liquid crystal element 12 are made equal in value, i.e., $R_1=R_2=R$. This also allows the use of switching voltages, $+V$ and $-V$, of equal magnitude. In operation, the rows of LC elements are sequentially addressed. For example, to address the row of LC elements, $LC_{1,1}$, $LC_{1,2}$ and $LC_{1,3}$, pulse voltages $+V$ and $-V$ are applied to the terminals X_1' and X_1'', respectively, and video input signals are simultaneously applied to terminals Y_1, Y_2 and Y_3, allowing the liquid crystal elements of this row to be charged in accordance with the magnitude of the signal voltages. During the next time interval, pulses $+V$ and $-V$ are applied to terminals X_2' and X_2'' while video input signals are again applied to terminals Y_1, Y_2 and Y_3, resulting in signal voltages appearing across the liquid crystal elements, $LC_{2,1}$, $LC_{2,2}$ and $LC_{2,3}$. In a similar manner, the remaining rows of the array are addressed.

As is commonly the practice in other liquid crystal displays, it may be desirable to reverse the polarity of the addressing signals, V_s, on successive frames to avoid any substantial dc bias from appearing across LC elements 12. In addition, if there is any unbalance in the conductivity of the two resistors 14 and 16 associated with a load element 12, a small voltage may appear at the junction M between them when the pulse voltages $+V$ and $-V$, are applied to the pairs of terminals X' and X'' of each row of elements. To avoid the effects of this, it may also be desirable, after each successive frame or groups of frames, to reverse the polarity of all the switching voltage pulses, $+V$ and $-V$, applied to the successive rows of load elements 12.

Although various types of nonlinear resistive materials are capable of fulfilling the above requirements, most of these require special preparation procedures such as vacuum deposition of materials or sintering at high temperature, making them incompatible with a polymer substrate. For example, although highly nonlinear resistive elements can be prepared by sintering together suitably doped grains of ZnO, this requires a firing temperature of about 1100° C., well above the melting point or decomposition temperatures of materials such as glass or plastic. The use and properties of such material is described in the paper, "2"×5" Varistor-Controlled Liquid Crystal Matrix Display", by D. E. Castleberry and L. M. Levinson in the 1980 *Digest of the Society for Information Display*, pp. 198–199. To overcome this restriction, the present invention is based on the use of powder binder nonlinear resistance elements composed of small particles of semiconductor or conductive material held in sufficiently close proximity to each other by an insulating or slightly conductive binder to allow current flow to occur such as by electron tunneling from particle to particle. An example of such a powder-binder nonlinear resistance material is described in the paper, "An Electroluminescent Digital Indicator With a Silicon Carbide Coding Matrix" by D. H. Mash in the *Journal of Scientific Instruments*, Vol. 37

pp. 47–50, 1960. In this case, commercially available silicon carbide powders were mixed with a resin binder, producing resistors whose current is proportional to the fifth power of the applied voltage.

Another example of a nonlinear resistor is described in the paper, "An Electroluminescent Light-Amplifying Picture Panel" by B. Kazan and F. H. Nicoll in the *Proceedings of the IRE*, Vol. 42, pp. 1888–1897, 1955, wherein a layer of the nonlinear resistive material, referred to as the "current-diffusing layer", is prepared by mixing a powder of CdS, whose particles have been doped with chlorine, for example, to make them conducting, with a binder of epoxy resin such as Araldite. Alternatively, other binder materials such as ethyl cellulose or polystyrene may be used in place of the epoxy resin. In all cases, however, it is desirable to dilute the resin with a volatile solvent. Upon evaporation of the solvent, the powder grains are then pulled tightly together by the remaining plastic or resin material, enhancing the flow of dc current between the grains. Resistor elements of such CdS materials typically have a current flow also proportional to the fifth or higher power of the applied voltage. It should be noted in this connection that, in large measure, the conductivity of the resultant samples and the degree of nonlinearity of their current-voltage characteristics can be controlled by the choice of particle size, the conductivity of the grains and the amount of plastic or resin material added to a given amount of the semiconductor powder.

An example of the physical construction of a display panel incorporating the circuit arrangement of FIG. 3 is shown in FIG. 4. Here the entire display is fabricated on the surface of a large area polymer sheet 13 in which are encapsulated tiny liquid crystal elements 12. Such polymer sheets are described in the paper, "Polymer Encapsulated Nematic Crystals for Display and Light Control Applications" by J. L. Fergason in the 1985 *Digest of the Society For Information Display*, pp. 68–70 and in the paper, "Polymer Encapsulated Nematic Crystals for Use in High Resolution and Color Displays" by J. L. Fergason in the 1986 *Digest of the Society For Information Display*, pp. 126–127.

As indicated in FIG. 4, the display 30 comprises upper electrodes 17, E_1, E_0, E_2 and leads 23A and 23B which are first deposited on the surface of the liquid crystal polymer sheet 13 preferably by a thick-film process. The two nonlinear resistor elements associated with each picture element are then fabricated as a thin layer on the surface of polymer sheet 13 between electrodes E_1 and E_0 and between E_2 and E_0, respectively. Resistors 14 and 16, for example, 10–20 μm thick, can also be fabricated by silk screening or other thick-film deposition method. Although electrodes 17 may be deposited in direct contact with liquid crystal polymer sheet 13, it may be desirable before depositing electrodes 17 to coat all other areas of sheet 13 with a thin insulating film 30A of resin or other material to better electronically isolate the nonlinear resistive elements and remaining conducting elements from the underlying liquid crystal polymer sheet 13.

On the opposite or lower surface of sheet 13, transparent conductive electrode strips 15 are provided in registry with the columns of electrodes 17 on the top surface of sheet 13. Top electrodes 17 together with bottom electrodes 15 serve to define the active areas of liquid crystal elements 12. As shown in FIG. 4, transparent electrodes 15 are connected respectively to terminals Y_1, Y_2 and Y_3 to enable electrical addressing of elements 12. Electrodes 15, comprising, for example, indium tin oxide, may be deposited on the rear surface of sheet 13 by well known techniques described in the prior art. However, instead of fabricating electrodes 15 directly on the surface of sheet 13, the lower surface of sheet 13 may be laminated to a thin glass plate of equal area on whose surface transparent electrode strips have been previously deposited or fabricated.

In the case where sheet 13 contains nematic crystal micro-capsules, display device 30 may be viewed in operation by reflected light from the bottom side of sheet 13, through transparent electrodes 15. In this case, it may be desirable for electrodes 17 to be light absorbing, comprising, for example, carbon black in an organic binder, so that liquid crystal elements 12 switched on by addressing signals would become transparent and appear black, while other areas of sheet 13 would appear white or cloudy as a result of the light scattering in these areas. Alternatively, electrodes 17 may be made of a transparent conducting material so that display device 30 may be viewed by transmitted light from either side, using, for example, a broad area light source for rear illumination.

Alternatively, liquid crystal sheet 13 may contain liquid crystal microcapsules with pleochroic dyes, also allowing display 30 to be viewed by reflecting or transmitted light. For producing a full color image, the microcapsules may contain a pleochroic dye mixture which appears opaque black in the OFF state and transparent in the ON state. In this case, successive rows or columns of electrodes 17, which are transparent, may be coated with red, blue and green color filters respectively. Illuminated with a broad area source of white light of selective electroded areas 17 of successive rows or columns may be made to transmit or reflect red, green and blue light respectively. Thus, in accordance with the electrical input signals, a full color image can be produced. To avoid undesired light from reaching the eye from outside the area of electrodes 17 and their corresponding LC elements 12, an opaque mask with apertures in registry with electrodes 17 may be placed over sheet 13.

While the invention has been described in conjunction with a few specific embodiments, it is evident to those skilled in the art that many alternatives, modifications and variations will be apparent in light of the foregoing description. For example, although all of the above discussion has been confined to displays of the liquid crystal type, it should be recognized that the use of nonlinear resistor elements as described above can be used for controlling other types of light modulating elements such as those consisting of electroluminescent thin films, powder electroluminescent layers, electrophoretic layers and electrochromic films as well as controlling a variety of marking or printing elements such as thermal elements, ink jet elements or impact printing elements. Accordingly, the invention is intended to embrace all such alternatives, modifications and variations as fall within the spirit and scope of the appended claims.

What is claimed is:

1. A control circuit for a load element comprising:

a pair of powder-binder nonlinear resistor elements formed on a surface of a substrate and having one terminal thereof connected to a common electrical junction,

said junction connected to said load element, the other terminals of said resistor element pair connected to switching voltage means,

the impedance at said common electrical junction being controlled in accordance with switching voltages applied to said other terminals of said resistor pair,

said powder-binder resistor elements comprising a non-sintered mixture of a conductive or semiconductive powder particles remaining bonded together with an insulating or low conductivity binder containing a volatile solvent to hold said particles together,

said binder remaining intact in said non-sintered mixture after evaporation of said solvent and serving to draw said particles together allowing limited current flow through said non-sintered mixture.

2. The control circuit of claim 1 wherein said conductive powder comprises silicon carbide, cadmium sulfide or zinc oxide particles.

3. The control circuit of claim 2 wherein said binder comprises epoxy resin, ethyl cellulose or polystyrene.

4. The control circuit of claim 1 wherein said load element is an electro-optical display element.

5. The control circuit of claim 4 wherein said electro-optical display element is a polymer-encapsulated liquid crystal material.

6. The control circuit of claim 1 wherein said load element is a printing element.

7. A liquid crystal display comprising

a sheet of micro-encapsulated liquid crystal material,

a plurality of elongated transparent electrodes formed on one surface of said sheet,

an array of pixel electrodes provided on the other surface of said sheet in registry with said elongated electrodes and defining a corresponding array of liquid crystal elements,

a plurality of pairs of powder-binder nonlinear resistor elements formed on said other surface of said sheet, each of said elements comprising a non-sintered mixture of a conductive or semiconductive powder particles bonded together with an insulating or low conductivity organic binder containing a volatile solvent to hold said particles together,

said non-sintered mixture forming said nonlinear resistor elements applied to said other surface of said sheet wherein said binder remains in said mixture after evaporation of said solvent and serving to draw said particles together allowing current flow through said non-sintered mixture,

each of said nonlinear resistor element pairs positioned adjacent to a corresponding pixel electrode and with a common junction of each pair connected to a corresponding pixel electrode, the other terminals of said resistor element pairs connected to switching voltage means to receive applied switching voltages,

said resistor element pairs having a nonlinear impedance characteristic whereby the current increases therethrough at a higher than linear rate as a function of said applied switching voltages,

said other terminals of groups of said nonlinear resistor element pairs connected together in parallel to a common pair of conducting leads allowing a separate switching voltage to be connected to each group,

addressing voltage signals applied to said elongated electrodes,

said switching voltage applied to said conductive leads of selected group of said nonlinear resistor element pairs to control their nonlinear impedance.

8. The liquid crystal display of claim 7 including an opaque layer with apertures in registry with said pixel electrodes.

9. The liquid crystal display of claim 7 wherein said nonlinear resistor element pairs are located in regions on said sheet which are not above said elongated electrodes.

10. The liquid crystal display of claim 7 wherein said nonlinear resistor elements comprise a silicon carbide powder, cadmium sulfide powder or zinc oxide powder.

11. The liquid crystal display of claim 7 wherein an insulating layer is formed on selected areas of said other surface of said sheet of micro-encapsulated liquid crystal material except in the regions beneath said pixel electrodes.

12. The liquid crystal display of claim 7 wherein the polarity of the switching voltages applied across said other terminal of said resistor element pairs is periodically reversed.

13. The liquid crystal display of claim 7 wherein the polarity of the addressing voltage signals applied to said elongated electrodes is reversed on successive addressing frames thereof.

14. The liquid crystal display of claim 7 wherein said applied switching voltages are adjusted so that the potential at said junction remains close to or at zero.

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United States Patent [19]

Pearlman et al.

[11] **Patent Number: 5,216,530**

[45] **Date of Patent: Jun. 1, 1993**

[54] **ENCAPSULATED LIQUID CRYSTAL HAVING A SMECTIC PHASE**

[75] Inventors: **Kenneth N. Pearlman**, San Jose; **James L. Fergason**, Atherton; **Ning S. Fan**, Cupertino, all of Calif.

[73] Assignee: **Taliq Corporation**, Sunnyvale, Calif.

[21] Appl. No.: **449,982**

[22] Filed: **Dec. 13, 1989**

Related U.S. Application Data

[63] Continuation of Ser. No. 140,930, Dec. 22, 1987, abandoned, which is a continuation of Ser. No. 740,218, Jun. 3, 1985.

[51] **Int. Cl.^{5}** **C09K 19/00; G02F 1/13**

[52] **U.S. Cl.** **359/43; 252/299.01; 252/299.1; 252/299.7; 428/1; 359/51**

[58] **Field of Search** 252/299.01, 299.1, 299.7; 359/43, 51, 52, 98; 428/1

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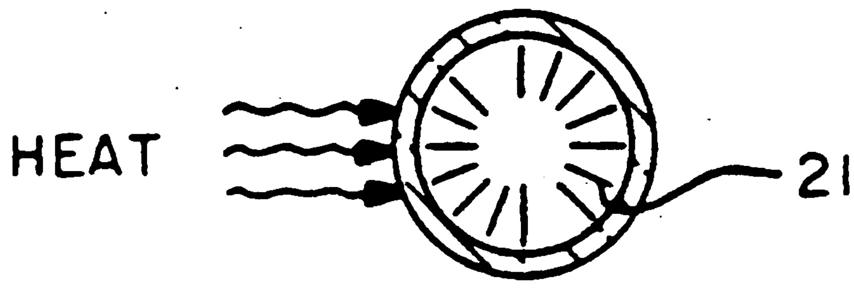
Primary Examiner—Robert L. Stoll
Assistant Examiner—Shean C. Wu
Attorney, Agent, or Firm—Heller, Ehrman, White & McAuliffe

[57] **ABSTRACT**

Briefly, according to one aspect of the invention, liquid crystal material having a smectic phase is encapsulated; and according to further aspects there are provided methods for encapsulating liquid crystal material having a smectic phase and for making a liquid crystal device using such encapsulated liquid crystal material.

8 Claims, 1 Drawing Sheet



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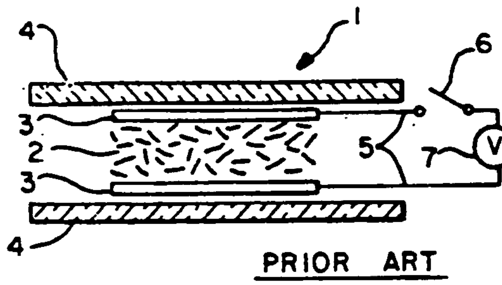

FIG.-1

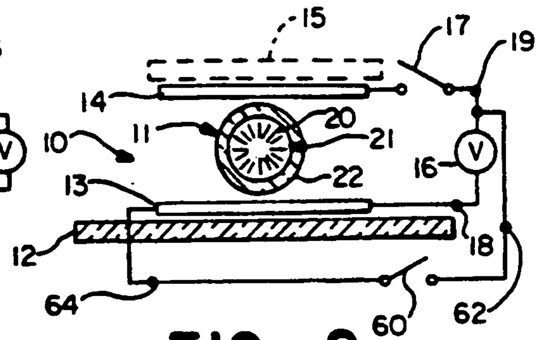

FIG.-2

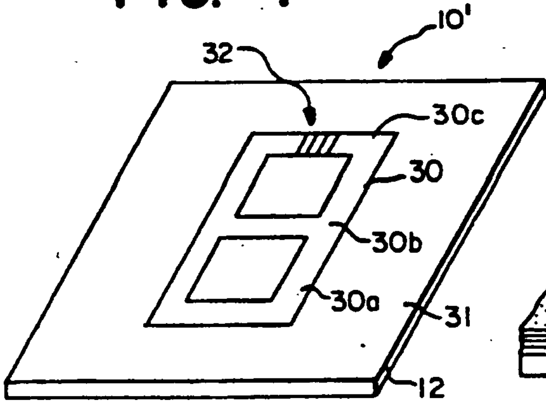

FIG.-3

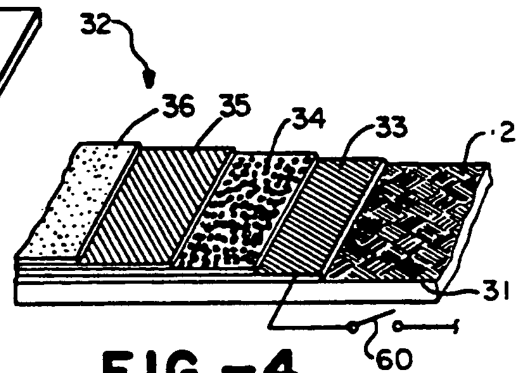

FIG.-4

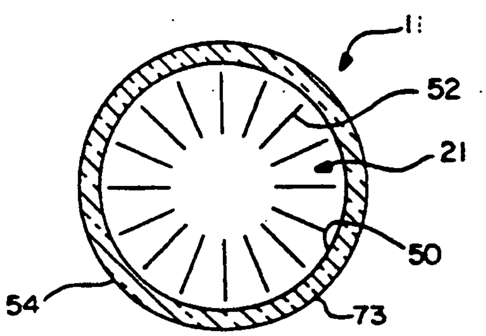

FIG.-5

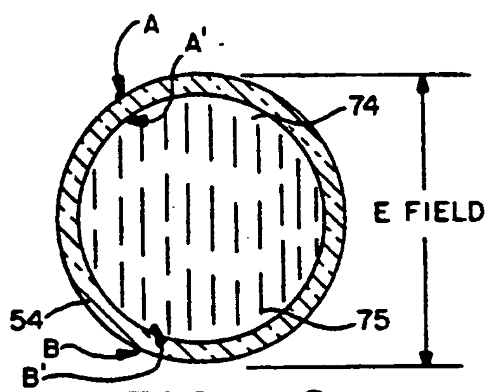

FIG.-6

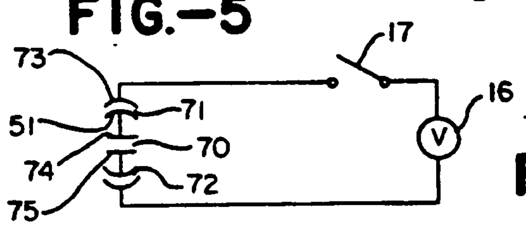

FIG.-7

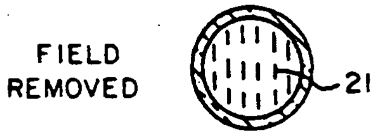

FIG.-8a

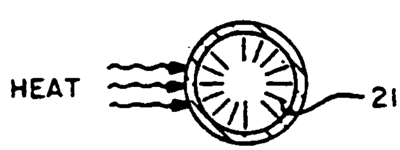

FIG.-8b

ENCAPSULATED LIQUID CRYSTAL HAVING A SMECTIC PHASE

This is a continuation of application Ser. No. 140,930 filed Dec. 22, 1987, now abandoned, which, in turn, is a continuation of application Ser. No. 740,218, filed Jun. 3, 1985, and now abandoned.

TECHNICAL FIELD

The present invention relates generally to liquid crystals and, more particularly, to encapsulated liquid crystals having a smectic phase. Moreover, the invention relates to devices using such encapsulated liquid crystals and to methods of making such encapsulated liquid crystals and devices.

BACKGROUND

Liquid crystals currently are used in a wide variety of devices, including optical devices such as visual displays. Such devices usually require relatively low power and have a satisfactory response time, provide reasonable contrast, and are relatively economical. The property of liquid crystals enabling use, for example, in visual displays, is the ability of liquid crystals to transmit light on one hand, and to scatter and/or absorb light, on the other, depending on the alignment (or lack of alignment) of the liquid crystal structure with, e.g., an electric field applied across the liquid crystal material. An example of electrically responsive liquid crystal material and use thereof is provided in U.S. Pat. No. 3,322,485.

Certain liquid crystal material is responsive to temperature, changing optical characteristics in response to temperature of the liquid crystal material.

The present invention is disclosed hereinafter particularly with reference to the use of liquid crystal material that is particularly responsive to an electric field as well as to temperature.

Currently there are three categories of liquid crystal materials, namely cholesteric, nematic and smectic types. The invention of the present application relates in the preferred embodiment described below to use of liquid crystal material having a smectic phase. The invention may also be employed with a liquid crystal material having a smectic as well as a nematic phase.

The various characteristics of the cholesteric, nematic and smectic types of liquid crystal material are described in the prior art. One know characteristic of liquid crystal material is that of reversibility; in particular it is noted here that nematic liquid crystal material is known to be reversible, but cholesteric material is not reversible. One characteristic of a reversible nematic material is that the liquid crystal structure will return to its original configuration after an electric field, for example, has been applied and then removed. On the other hand, smectic material will retain its configuration even after removal of an electric field.

To enhance contrast and possibly other properties of liquid crystal material, pleochroic dyes have been mixed with the liquid crystal material to form a solution therewith. The molecules of the pleochroic dye generally align with the molecules of the liquid crystal material. Therefore, such pleochroic dyes will tend to function optically in a manner similar to that of the liquid crystal material in response to a changing parameter, such as application or non-application of an electric field or heat. Examples of the use of pleochroic dyes with liquid crystal material are described in U.S. Pat. Nos. 3,499,702 and 3,551,026.

An important characteristic of liquid crystal material is anisotropy. An anisotropic material has different physical properties in different directions. For example, liquid crystals are optically anisotropic, i.e., they have indices of refraction which vary with the direction of propagation and polarization of the incident light.

Liquid crystal material also has electrical anisotropy. For example, the dielectric constant for smectic liquid crystal material may be one value when the molecules in the liquid crystal structure are parallel to the electric field and may have a different value when the molecules in the liquid crystal structure are aligned perpendicular to an electric field. Since such dielectric value is a function of alignment, for example, reference to the same as a "dielectric coefficient" may be more apt than the usual "dielectric constant" label. Similar properties are true for other types of liquid crystals.

Some brief discussion of the encapsulation of cholesteric liquid crystal material is presented in U.S. Pat. Nos. 3,720,623, 3,341,466, and 2,800,457, the latter two patents being referred to in the first named patent.

In the past, devices using liquid crystals, such as visual display devices or other devices, have been of relatively small size. Large size devices using liquid crystals, such as, for example, a billboard display or a sign have not been satisfactorily fabricatable for a number of reasons. One reason is the fluidity of the liquid crystals, (the liquid crystal material may tend to flow creating areas of the display that have different thicknesses). As a result, the optical characteristics of the display may lack uniformity, have varying contrast characteristics at different portions of the display, etc. The thickness variations in turn cause variations or gradations in optical properties of the liquid crystal device. Moreover, the varying thickness of the liquid crystal layer will cause corresponding variations in the electrical properties of the liquid crystal layer, such as capacitance and impendance, further reducing uniformity of a large size liquid crystal device. The varying electrical properties of the liquid crystal layer, then, also may cause a corresponding variation in the effective electric field applied across the liquid crystal material and/or in response to a constant electric field would respond differently at areas of the liquid crystal that are of different thicknesses.

A pleochroic display, i.e., one in which pleochroic dye and liquid crystal material are in solution together, has the advantage of not requiring the use of a polarizer. However, such a pleochroic device has a disadvantage of relatively low contrast when only nematic liquid crystal material is used. It was discovered in the past, though, that a cholesteric liquid crystal material could be added to the nematic one together with the dye to improve the contrast ratio. See White et al. article, *Journal of Applied Physics*, Volume 45, No. 11, November 1974, at pages 4718–4723, for example. The cholesteric material would tend not to return to its original zero field form when the electric field is removed.

Another problem encountered with pleochroic dye included in solution with liquid crystal material, regardless of the particular type of liquid crystal material, is that the light absorption of the dye is not zero in the "field-on" condition. Rather such absorption in the "field-on" condition follows a so-called ordering parameter, which relates to or is a function of the relative alignment of the dyes. The optical transmission charac-

teristic of liquid crystal material is an exponential function of the thickness of the liquid crystal material. Specifically, the "on" state or "field-on" or "energized" state of the liquid crystal material is an exponential function of the thickness of the liquid crystal material, and the "absorbing" state or "field-off" state also is a different exponential function of the thickness.

To overcome those problems described in the two immediately preceding paragraphs, the liquid crystal material should have an optimum uniform thickness. (As used herein the term "liquid crystal" material means the liquid crystals themselves and, depending on context, the pleochroic dye in solution therewith). There also should be an optimum spacing of the electrodes by which the electric field or heat is applied to the liquid crystal material. To maintain such optimum thickness and spacing, rather close tolerances must be maintained. To maintain close tolerances, there is a limit as to the size of the device using such liquid crystals, for it is quite difficult to maintain close tolerances over large surface areas, for example.

BRIEF SUMMARY OF THE INVENTION

Briefly, according to one aspect of the invention, liquid crystal material having a smectic phase is encapsulated. According to another aspect, the encapsulated liquid crystal material is used in liquid crystal devices, such as visual display devices and optical shutters. And according to further aspects there are provided methods for encapsulating liquid crystal material and for making a liquid crystal device using such encapsulated liquid crystal material.

A liquid crystal having both a smectic and nematic phase may also be encapsulated in accordance with the present invention. The transition temperature of the liquid crystal material determines whether it is in the smectic or nematic phase. In the nematic phase, the liquid crystal is operationally nematic, as defined below and in U.S. Pat. No. 4,435,047, issued Mar. 6, 1984, in the name of Fergason and entitled ENCAPSULATED LIQUID CRYSTAL AND METHOD, which is hereby incorporated by reference.

By "operationally nematic" is meant that, in the absence of external fields, structural distortion of the liquid crystal is dominated by the orientation of the liquid crystal at its boundaries rather than by bulk effects, such as very strong twists (as in cholesteric material) or layering (as in smectic material). Thus, for example, chiral ingredients which induce a tendency to twist but cannot overcome the effects of boundary alignment would still be considered operationally nematic. Such operationally nematic liquid crystal material may include pleochroic dyes, chiral compounds, or other co-ingredients.

A capsule as used herein generally refers to a containment device or medium that confines a quantity of liquid crystal material, and "encapsulating medium" or "material" is that medium or material of which such capsules are formed. An "encapsulated liquid crystal" or "encapsulated liquid crystal material" means a quantity of liquid crystal material confined or contained in discrete volumes within the encapsulating medium, for example in a solid medium as individual capsules or dried stable emulsions. The discrete volumes, however, may also be interconnected, for example, by one or more passages. The liquid crystal would preferably be in both the discrete volumes and interconnecting passages. Thus, the internal volumes of respective capsules may be fluidly coupled via one or more interconnecting passages.

Capsules according to this invention generally have an approximately spherical configuration (though this is not, per se, a requisite of the invention) having a diameter from about 0.3 to 100 microns, preferably 0.1 to 30 microns, especially 3 to 15 microns, for example 5 to 15 microns. In the context of this invention, encapsulation and like terms refer not only to the formation of such articles as are generally referred to as capsules, but also to the formation of stable emulsions or dispersions of the liquid crystal material in an agent (an encapsulating medium) which results in the formation of stable, preferably approximately uniformly sized, particles in a uniform surrounding medium. Techniques for encapsulation, generally referred to as microencapsulation because of the capsule size, as well known in the art (see, e.g., "Microcapsule Processing and Technology" by Asaji Kondo, published by Marcel Dekker, Inc.) and it will be possible for one skilled in the art, having regard to the disclosure herein, to determine suitable encapsulating agents and methods for liquid crystal materials.

A liquid crystal device is a deviced formed of liquid crystal material. In the present invention such devices are formed of encapsulated liquid crystals having a smectic phase capable of providing a function of the type typically inuring to liquid crystal material; for example, such a liquid crystal device may be a visual display or an optical shutter that in response to application and removal of an electric field and heat effects a selected attenuation of optical radiation, preferably including from far infrared through ultraviolet wavelengths.

One method of making encapsulated liquid crystals includes mixing together liquid crystal material having a smectic phase and an encapsulating medium in which the liquid crystal material will not dissolve and permitting the formation of discrete capsules containing the liquid crystal material.

A method of making a liquid crystal device including such encapsulated liquid crystal includes, for example applying such encapsulated liquid crystal material to a substrate. Moreover, such method includes providing means for applying an electric field and heat to the liquid crystal material to affect a property thereof.

According to another feature of the invention a liquid crystal material having a smectic phase in which is dissolved a pleochroic dye is placed in a generally spherical capsule. In the absence of an electric field, the capsule wall distorts the liquid crystal structure so it and the dye will tend to absorb light regardless of its polarization direction. When a suitable electric field is applied across such a capsule, for example across an axis thereof, the liquid crystal material will tend to align parallel to such field causing the absorption characteristic of such material to be reduced to one assumed when the liquid crystal material is in the planar configuration. To help assure that adequate electric field is applied across the liquid crystal material in the capsule, and not just across or through the encapsulating medium, and, in fact, with a minimum voltage drop across the wall thickness of the respective capsules, the encapsulating material preferably has a dielectric constant no less than the lower dielectric constant of the liquid crystal material, on the one hand, and a relatively large impedance, on the other hand. Ideally, the dielectric constant of the encapsulating medium should be close to the higher dielectric constant of the liquid crystal.

Contrast of a liquid crystal device employing encapsulated liquid crystals may be improved by selecting an encapsulating medium that has an index of refraction that is matched to the ordinary index of refraction of the liquid crystal material (i.e., the index of refraction parallel to the optical axis of the crystal). See, e.g. "Optics" by Born and Wolf, or "Crystal and the Polarising Microscope" by Hartshorne and Stewart. The encapsulated medium may be used not only to encapsulated liquid crystal material but also to adhere the capsules to a substrate for support thereon. Alternatively, a further binding medium may be used to hold the liquid crystal capsules relative to a substrate. In the latter case, though preferably the additional binding medium has an index of refraction which is matched to that of the encapsulating medium for maintaining the improved contrast characteristic described above. Because the index of refraction of a material is generally strain-dependent, and strain may be induced in, e.g., the encapsulating medium, it may be necessary to consider this effect in matching the indices of refraction of the liquid crystal, encapsulating medium, and binding medium, if present. Further, if iridescence is to be avoided, it may be desirable to match the indices of refraction over a range of wavelengths to the extent possible, rather than at just one wavelength.

A feature of the present invention is that the molecules of the liquid crystal material in the smectic phase prior to the application of an electric field thereto tend to align themselves generally perpendicular to the curved surfaces of the spherical or otherwise curvilinear surfaced capsule. Accordingly, the liquid crystal structure tends to be forced or distorted to a specific form, generally focal conic, so that the resulting optical characteristic of a given capsule containing liquid crystal material is such that substantially all light delivered thereto will be affected, for example, scattered (when no pleochroic dye is present) or absorbed (when pleochroic dye is present), prior to the application of an electric field, regardless of the polarization direction of the incident light. Even without dye this effect can cause scattering and thus opacity.

Another feature of the present invention is the ability of the molecules of the smectic phase liquid crystal material to to align themselves in a direction parallel to an electric field applied thereto and to remain in that alignment after removal of the electric field. When aligned in this manner, the liquid crystal material reduces the amount of scattering or absorption of light that would otherwise be present. The subsequent application of sufficient heat to the liquid crystal material induces the generally distorted alignment of the liquid crystal material such that light is scattered or absorbed. The temperature at which this occurs may be the smectic to nematic phase transition temperature or the smectic to isotropic phase transition temperature. This concept may be called heat-to-erase.

Another feature of the present invention relies on the concept of a thermally activated display. This display utilizes an encapsulated liquid crystal material having both a smectic and nematic phase. The liquid crystal is heated so that it is in the nematic phase, and an electric field is applied thereto to effect a visual display. The temperature of the liquid crystal is reduced so that it is in the smectic phase. The electric field is removed and the display remains. The display may be erased by heating the liquid crystal so that it is again in the nematic phase.

Yet another feature is the ability to control the effective thickness of the liquid crystal material contained in a capsule by controlling the internal diameter of such capsule. Such diameter control may be affected by a size fractionation separation process during the making of the encapsulated liquid crystals using any one of a variety of conventional or novel sorting techniques as well as by controlling the mixing process, the quantities of ingredients, and/or the nature of the ingredients provided during mixing. By controlling such thickness parameter to relatively close tolerances, then, the subsequent tolerance requirements when the final liquid crystal device is made using the encapsulated liquid crystals will not be as critical as was required in the past for nonencapsulated devices.

Moreover, a further feature of the present invention is that there appears to be no limitation on the size of a high quality liquid crystal device that can be made using the encapsulated liquid crystals in accordance with the present invention. More specifically, by providing for confinement of discrete quantities of liquid crystal material, for example, in the described capsules, the various problems encountered in the past that prevented the use of liquid crystal material in large size devices are overcome, for each individual capsule in effect can still operate as an independent liquid crystal device. Moreover, each capsule preferably has physical properties enabling it to be mounted in virtually any environment including one containing a plurality of further such liquid crystal capsules mounted to a substrate or otherwise supported for use in response to application and removal of some type of excitation source, such as, for example, an electric field or heat. This feature also enables placement of the liquid crystal material on only selected areas of the optical device, such as in large size displays (e.g., billboards), optical shutters, etc.

Important considerations in accordance with the invention are that an encapsulating medium having electrical properties matched in a prescribed way to the electrical properties of liquid crystal material encapsulated therby and additionally preferably optically matched to the optical properties of such liquid crystal material permits efficient and high quality functioning of the liquid crystal material in response to excitation or non-excitation by an external source; and that the interaction of the encapsulating medium with the liquid crystal material distorts the latter in a prescribed manner changing an operational mode of liquid crystal material.

An object of the invention is to enable the use of liquid crystal material having a smectic phase wherein that material is encapsulated and maintains relatively high quality of operation, controlled uniformity of output and satisfactory contrast.

Another object is to confine liquid crystal material having a smectic phase wherein a generally distorted alignment is induced that scatters or absorbs light and reduced in response to a prescribed input with such reduction remaining after removal of the prescribed input, thereby providing a display having memory.

Yet another object is to enable a display to be erased or heated by the application of heat to increase the temperature of the liquid crystal so that it is not in the smectic phase.

These and other objects and advantages of the present invention will become more apparent as the following description proceeds.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a prior art liquid crystal device;

FIG. 2 is a schematic representation of a liquid crystal device in accordance with the present invention;

FIG. 3 is an isometric view of a liquid crystal display device in accordance with the present invention;

FIG. 4 is an enlarged fragmentary view, partly broken away, of a portion of the liquid crystal display device of FIG. 3;

FIG. 5 is an enlarged schematic illustration of a liquid crystal capsule in accordance with the present invention under a no field condition;

FIG. 6 is a view similar to FIG. 5 under an applied electric field condition;

FIG. 7 is a schematic electric circuit diagram representation of the capsule with an applied field; and

FIGS. 8*a* and 8*b* are enlarged schematic illustrations of a liquid crystal capsule in accordance with the present invention under a field removed condition and under an applied heat condition, respectively.

SUMMARY OF A PRIOR ART LIQUID CRYSTAL DEVICE

Referring now in detail to the drawings, wherein like reference numerals designate like parts in the several figures, and initially to FIG. 1, a prior art liquid crystal device is generally indicated at 1. Such device 1 includes liquid crystal material 2 sandwiched between electrodes 3 of, for example, indium tin oxide that are deposited for support on respective mounting or confining substrates 4, such as glass, plastic sheets or the like. The sheets 4 may be clear as may be the electrodes 3 so that the device 1 is an optical transmission control device, whereby incident light may be absorbed and/or scattered when no electric field is applied by the electrodes 3 across a liquid crystal material 2 and the incident light may be transmitted through the liquid crystal material 2 when an electric field is applied thereacross. Electric leads 5 and switch 6 selectively couple voltage source 7 across the electrodes 3 to provide such electric field. The voltage source 7 may be either an AC or a DC voltage source.

The liquid crystal material 2 in the device 1 is somewhat confined by the substrates 4 for retention in a desired location, say for example, to be used overall as part of a digital display device. On the other hand, the liquid crystal material 2 must have adequate freedom of movement so that it may assume either a random orientation or distribution when no electric field is applied or a prescribed distributional or orientational alignment when an electric field is applied across the electrodes 3. If desired, one of the substrates 4 may be reflective to reflect incident light received through the liquid crystal material 2 back through the latter for delivery through the other substrate 4 for subsequent use. The various principles of operation and features and disadvantages of the liquid crystal device 1 are summarized above and are described in the prior art literature.

The liquid crystal material 2 may be of virtually any type that is responsive to an electric field applied thereacross so as to have a desired operating characteristic intended for the device 1. The liquid crystal material 2 also may include, if desired, pleochroic dye material in solution therewith.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to FIG. 2, an improved liquid crystal device in accordance with the present invention is indicated at 10. The device 10 includes an encapsulated liquid crystal 11 having a smectic phase which is supported by a mounting substrate 12 across which an electric field may be applied via electrodes 13, 14.

The electrode of 13 may be, for example, a quantity of vacuum deposited indium tin oxide applied to the substrate 12, and the electrode 14 may be, for example, electrically conductive ink. A protective layer or coating 15 may be applied over the electrode 14 for protective purposes but such layer 15 ordinarily would not be necessary for supporting or confining the encapsulated liquid crystal 11 or the electrode 14. Voltage may be applied to the electrodes 13, 14 from an AC or DC voltage source 16. A selectively closable switch 17 and electrical leads 18, 19 are utilized to apply an electric field across the encapsulated liquid crystal 11 when the switch 17 is closed. A second selectively closable switch 60 and electrical leads 62, 64 may be utilized to provide a resistive heating source for the application of heat to the liquid crystal material to increase the temperature thereof for the purposes hereinafter described. Switch 60 may be closed to cause a suitable current to flow through electrode 13 so as to heat the liquid crystal material to the desired level. Other techniques, such as a heat gun, may be utilized to heat the liquid crystal material.

The encapsulated liquid crystal 11 includes liquid crystal material 20 contained within the confines or interior volume 21 of a capsule 22. Preferrably, the capsule 22 is generally spherical. However, the principles of the invention would apply when the capsule 22 is of a shape other than spherical. Such shape should provide the desired optical and electrical characteristics that will satisfactorily coexist with the optical characteristics of the liquid crystal 20, e.g., index of refraction, and will permit an adequate portion of the electric field to occur across the liquid crystal material 20 itself for effecting desired alignment of the liquid crystal structure when it is desired to have a field on condition. A particular advantage to the preferred spherical configuration of the capsule 22 will be described below with respect to the distortion it effects on the liquid crystal structure.

The mounting substrate 12 and the electrodes 13, 14 as well as the protective coating 15 may be optically transmissive so that the liquid crystal device 10 is capable of controlling transmission of light therethrough in response to whether or not an electric field is applied across the electrodes 13, 14 and, thus, across the encapsulated liquid crystal 11. Alternatively, the mounting substrate 12 may be optically reflective or may have thereon an optically reflective coating so that reflection by such reflective coating of incident light received through the protective coating 15 will be a function of whether or not there is an electric field applied across the encapsulated liquid crystal 11.

Preferably, a plurality of encapsulated liquid crystals 11 would be applied to the mounting substrate 12 in a manner such that the encapsulated liquid crystals adhere to the mounting substrate 12 or to an interface material, such as the electrode 13, for support by the mounting substrate 12 and retention in a fixed position relative to the other encapsulated liquid crystals 11.

Most preferably the encapsulating medium of which the capsule 22 is formed is also suitable for binding or otherwise adhering the capsule 22 to the substrate 12. Alternatively, a further binding medium (not shown) may be used to adhere the encapsulated liquid crystals 11 to the substrate 12. Since the capsules 22 are adhered to the substrate 12, and since each capsule 22 provides the needed confinement for the liquid crystal material 20, a second mounting substrate, such as the additional one shown in the prior art liquid crystal device 1 of FIG. 1, ordinarily would be unnecessary. However, for the purpose of providing protection from scarring, electrochemical deterioration, e.g., oxidation, or the like, of the electrode 14, a protective coating 15 may be provided on the side or surface of the liquid crystal device 10 opposite the mounting substrate 12, the latter providing the desired physical protection on its own side of the device 10.

Since the encapsulated liquid crystals 11 are relatively securely adhered to the substrate 12 and since there ordinarily would be no need for an additional substrate, as mentioned above, the electrode 14 may be applied directly to the encapsulated liquid crystals 21.

Turning now to FIG. 3, an example of a liquid crystal device 10' in accordance with the invention is shown in the form of a liquid crystal display device, which appears as a square cornered figure eight 30 on the substrate 12, which in this case preferably is of a plastic material, such as Mylar, or may alternatively be another material, such as glass, for example. The shaded area appearing in FIG. 3 to form the square cornered figure eight is formed of plural encapsulated liquid crystals 11 arranged in one or more layers on and adhered to the substrate 12.

An enlarged fragmentary section view of a portion 32 of the figure eight 30 and substrate 12 is illustrated in FIG. 4. As is seen in FIG. 4, on the surface 31 of the substrate 12, which may be approximately 10 mils thick, is deposited a 200 angstrom thick electrode layer 33 of, for example, indium tin oxide or other suitable electrode material such as gold, aluminum, tin oxide, antimony tin oxide, etc. One or more layers 34 of plural encapsulated liquid crystals 11 are applied and adhered directly to the electrode layer 33. Such adherence is preferably effected by the encapsulating medium that forms respective capsules 22, although, if desired, as was mentioned above, an additional adhering or binding material may be used for such adherence purposes. The thickness of the layer 34 may be, for example, approximately 0.3 to 10 mils, preferably 0.7 to 4 mils, more preferably 0.8 to 1.2 mils, especially 1 mil. Other thicknesses may also be used, depending inter alia on the ability to form a thin film and the electrical breakdown properties of the film. A further electrode layer 35 is deposited on the layer 34 either directly to the material of which the capsules 22 are formed or, alternatively, to the additional binding material used to bind the individual encapsulated liquid crystals 11 to each other and to the mounting substrate 12. The electrode layer 35 may be, for example, approximately ½ mil thick and may be formed, for example, of electrically conductive ink or of the materials mentioned above for layer 33. A protective coating layer 36 for the purposes described above with respect to the coating 15 in FIG. 3 also may be provided as is shown in FIG. 4.

In a conventional visual display device either of the liquid crystal or light emitting diode type, the figure eight element 30 ordinarily would be divided into seven electrically isolated segments, each of which may be selectively energized or not so as to create various numeral characters. For example, energization of the segments 30a and 30b would display the numeral "1", and energization of the segments 30a, 30b, and 30c would display the numeral "7".

A feature of the present invention utilizing the encapsulated liquid crystals 11 is that a versatile substrate 12 can be created to be capable of displaying virtually any desired display as a function of only the selective segments of conductive ink electrodes printed on the liquid crystal material. In this case, the entire surface 31 of the substrate 12 may be coated with electrode material 33, and even the entire surface of that electrode material may be coated substantially contiguously with layer 34 of encapsulated liquid crystals 11. Thereafter, a prescribed pattern of electrode segments of conductive ink 35 may be printed where desired on the layer 34. A single electrical lead may attach the surface 31 to a voltage source, and respective electrical leads may couple the respective conductive ink segments via respective controlled switches to such voltage source. Alternatively, the encapsulated liquid crystals 11 and/or the electrode material 33 may be applied to the surface 31 only at those areas where display segments are desired. The ability to apply encapsulated liquid crystal to only a desired area or plurality of areas such as the segments of a display by essentially conventional processes (such as e.g. silk-screening or other printing processes) is particularly attractive, when compared with the prior art, which has the problem of containing liquid crystals between flat plates.

Although a detailed description of the operation of the individual encapsulated liquid crystals 11 will be presented below, it will suffice here to note that the encapsulated liquid crystals in the layer 34 function to attenuate or not to attenuate light incident thereon. A pleochroic dye may be present in solution in the liquid crystal material to provide substantial attenuation by absorption prior to the application of the field but to be substantially transparent after the field has been applied. Such an electric field may be, for example, one produced as a result of the coupling of the electrode layer portions 33, 35 at an individual segment, such as segment 30a, of the liquid crystal device 10' to an electrical voltage source. the magnitude of the electric field required to switch the encapsulated liquid crystals 11 from a no field (deenergized) condition to a field-on (energized) condition may be a function of several parameters, including, for example, the diameter of the individual capsules and the thickness of the layer 34, which in turn may depend on the diameter of individual capsules 22 and the number of such capsules in the thickness direction of layer 34. Importantly, it will be appreciated that since the liquid crystal material 20 is confined in respective capsules 22 and since the individual encapsulated liquid crystals 11 are secured to the substrate 12, the size of the liquid crystal device 10' or any other liquid crystal device employing encapsulated liquid crystals in accordance with the present invention is virtually unlimited. Of course, at those areas where it is intended to effect a change in the optical properties of the encapsulated liquid crystals of such a device in response to a no field or field on condition, it would be necessary to have at such areas electrodes or other means for applying to such liquid crystals a suitable electric field.

The electrode layer 33 may be applied to the substrate 12 by evaporation, by vacuum deposition, by sputtering, by printing or by another conventional technique. Moreover, the layer 34 of encapsulated liquid crystals 11 may be applied, for example, by a web or gravure roller or by reverse roller printing techniques. The electrode layer 35 also may be applied by various printing, stenciling or other techniques. If desired, the electrode layer 33 may be prepared as a full coating of the substrate 12, such as Mylar, as described above, as part of the process in which the Mylar sheet material is manufactured, and the layer 34 also may be applied as part of such manufacturing process. Electrode 33 may be attached to a voltage source through a selectively closable switch 60 separate from the respective controlled switches utilized to energize the conductive segments. When switch 60 is pulsed closed, electrode 33 functions as a resistive heating element that applies heat to the liquid crystal material to increase the temperature thereof.

If the liquid crystal material has both a smectic and nematic phase, heat may be applied, by closing switch 60, to heat the liquid crystal through its transition temperature where it changes from the smectic to the nematic phase. Thereafter, an electric field (across electrodes 33, 35) can be applied to the liquid crystal material, now in the nematic phase, such that the liquid crystal material is substantially transparent to effect a visual display, such as the numeral "1". (See FIG. 6). The temperature of the liquid crystal may then be reduced, by opening switch 60, so that the liquid crystal is in the smectic phase. The electric field may then be removed. The display, however, will be retained (See FIG. 8*a*), e.g., the numeral "1", since the molecules of the liquid crystal in the smectic phase are not free to change direction and the liquid crystal is more viscous in this phase. The above-described concept may be called a thermally-activated display.

To erase the display, switch 60 may again be pulsed closed to heat the liquid crystal above its transition temperature where it is in the nematic phase. As discussed, in the nematic phase, incident light is absorbed or scattered in the absence of an electric field (See FIG. 8*b*). Thus, the display is effectively erased. The display may also be erased by heating the liquid crystal so that it is in its isotropic phase wherein incident light is scattered or absorbed.

A liquid crystal material having only a smectic phase may also be utilized in the concept of the present invention. The smectic phase may either be smectic A phase or smectic C phase. The smectic C phase operates at lower voltages than smectic A, and the smectic C phase may have a chiral character. An electric field may be applied across the liquid crystal in the smectic phase to eliminate the scattering or absorption of light otherwise present (See FIG. 6). The display formed by the application of the electric field, such as the numeral "1", remains after the field is removed (See FIG. 8*a*). The display may be thereafter erased by heating the liquid crystal to a temperature above the smectic to isotropic phase transition temperature. Alternatively, it may be erased by heating it to a temperature above the smectic to nematic phase transition temperature. This display concept may be called the heat-to-erase concept. It differs from the thermally-activated display in that the field is applied and display effected with the liquid crystal in the smectic phase.

The smectic phase encapsulated system which operates at moderate voltages can be used to form a novel type of display. The principle is based on the above-described ability of smectic liquid crystal to store indefinitely when exposed to an electric field. Thus a display can be made using a matrix of elements, such that there is a cross-grid formed. A permanent pattern can be formed on the cross-grid by elevating voltage on the lines and rows to be written, simultaneously. Thus, rows not written can be put at a voltage which is close to that of the columns. The same voltage, with opposite polarity, can be put on those rows to be written, so that a voltage appears across the column/row intersection which is two times greater than that applied to rows which are not to be written.

If this process is carried out in sequence at a rate sufficiently slow so that RMS increases in voltage do not occur across row/column intersections, then a pattern can be formed which will remain in place until such time as the display is heated (to erase) to the phase transition of the smectic liquid crystal.

The heat-to-erase and the thermally-activated displays are especially suitable for use in display devices where there is relatively long time periods between changes in or updates of the display. The displays may also be used as a temperature indicating label to indicate when there is a temperature rise above a certain level. For example, certain chemicals must be stored below a given temperature. A label reading "OK," e.g., may be applied to a container holding the chemicals. The "OK" display would disappear or be erased when the temperature rises above the undesirable or even dangerous level.

The ability to make and to use successfully heat-to-erase and thermally activated liquid crystal devices of the type just described is in part due to the ability to make encapsulated liquid crystals and to the properties of such encapsulated liquid crystals, both of which are features of the present invention. These features now will be described. Referring specifically to FIG. 5, the capsule 22 has a generally smooth curved interior wall surface 50 defining the boundary of the volume 21. The actual dimensional parameters of the wall surface 50 and of the overall capsule 22 are related to the quantity of liquid crystal material 20 contained therein. Additionally, the capsule 22 applies a force to the liquid crystals 20 tending to pressurize or at least to maintain substantially constant the pressure within the volume 21. As a result of the foregoing, and due to the surface wetting nature of the liquid crystal, the structure which ordinarily in free form would tend to be straight, although perhaps randomly distributed, is distorted to have a generally focal conic form. Due to such distortion the liquid crystals store elastic energy. For simplicity of illustration, and for facility of comprehending the foregoing concept, the liquid crystal molecules whose directional orientation is represented by respective dashed lines 52 is shown as having a bulk alignment wherein the liquid crystal molecules radiate from a central portion of the capsule to be generally (perpendicular to a relatively proximate portion of) the interior wall surface 50.

Thus, the organization of liquid crystal molecules in an individual capsule is determined by the bulk alignment of the molecules within the capsules unless acted on by outside forces, e.g., an electric field. As noted heretofore, on removal of the field, the directional orientation illustrated in FIG. 6 of the smectic liquid crys-

tal remains (See FIG. 8a). The distorted alignment depicted in FIG. 5 returns upon the application of heat to the liquid crystal to heat it above the phase transition temperature (See FIG. 8b). The liquid crystal molecules have a smectic phase. Such molecules usually assume a parallel configuration, and a liquid crystal material comprised of such molecules usually is optical polarization direction sensitive. However, since the structure 52 in the encapsulated liquid crystal 11 is distorted or forced to assume focal conic form shown in FIGS. 5 or 8b in the full three dimensions of the capsule 22, such liquid crystal material in such capsule takes on an improved characteristic of being insensitive to the direction of optical polarization of light incident thereon. Moreover, when the liquid crystal material 20 in the capsule 22 has pleochroic dye dissolved therein, such dye, which ordinarily also would be expected to have optical polarization sensitivity, no longer is polarization sensitive because the dye tends to follow the same kind of orientation or distortion as that of the liquid crystal structure.

With the liquid crystal structure being distorted generally in the manner illustrated in FIGS. 5 and 8b, the encapsulated liquid crystal 11 oridinarily will absorb or block light from being transmitted therethrough prior to the application of an electric field across the encapsulated liquid crystal 11 and particularly across the liquid crystal material 20 thereof.

Although the foregoing discussion has been in terms of a homogeneous orientation of the liquid crystal material, such is not a requisite of the invention. All that is required is that the interaction between the capsule and the liquid crystal produce an orientation in the liquid crystal that is generally uniform and piecewise continuous, so that the spatial average orientation of the liquid crystal material over the capsule volume is generally focal conic and there is no substantial parallel directional orientation of the liquid crystal in the absence of an electric field. It is this orientation that results in the absorption/scattering and polarization insensitivity.

However, when an electric field is applied across the encapsulated liquid crystal 11 in the manner illustrated in FIG. 6, the liquid crystal and any pleochroic dye in solution therewith will align in response to the electric field in the manner shown in such figures. Such alignment permits light to be transmitted through the encapsulated liquid crystal 11, for example as described above with reference to FIGS. 2, 3 and 4.

When the electric field is removed, the alignment of the liquid crystal as shown in FIG. 6 remains. The application of heat to the liquid crystal as shown in FIG. 8b causes the liquid crystal to return to the distorted alignment illustrated in FIG. 5.

To optimize the contrast characteristics of a liquid crystal device, such as that shown at 10' in FIG. 3, comprised of encapsulated liquid crystals 11, and more particularly, to avoid optical distortion, due to refraction of incident light passing from the encapsulating medium into the liquid crystal material and vice versa, of the encapsulated liquid crystal 11 of FIG. 6, the index of refraction of the encapsulating medium and that the ordinary index of refraction of the liquid crystal material should be matched so as to be as much as possible the same. The closeness of the index matching will be dependent on the desired degree of contrast and transparency in the device, but the ordinary index of refraction of the crystal and the index of the medium will preferably differ by no more than 0.03, more preferably 0.01, especially 0.001. The tolerated difference will depend on capsule size and intended use of the device. The text "Optics" by Sears, published by Addison-Wesley, contains a thorough discussion of birefringence relevant to the foregoing, and the relevant portions of such text are incorporated herein by reference.

However, when no field is applied there will be a difference in indices of refraction at the boundary of the liquid crystal and capsule wall due to the extraordinary index of refraction of the liquid crystal being greater than the encapsulating medium. This causes refraction at that interface or boundary and thus further scattering and is a reason why encapsulated liquid crystal material in accordance with the present invention, in particular, will function to prevent transmission of light even without the use of pleochoric dye.

Ordinarily the encapsulated liquid crystals 11 would be applied to the substrate 12 (FIG. 3) such that the individual encapsulated liquid crystals 11 are relatively randomly oriented and preferably several capsules thick to assure an adequate quantity of liquid crystal material on the surface 31 of the substrate to thereby provide the desired level of light blockage and/or transmission characteristics for, for example, a liquid crystal device 10' or the like.

In a liquid crystal device, such as that shown in 10' in FIG. 3, which is comprised of liquid crystal material 20 including pleochroic dye to form encapsulated liquid crystals 11 according to the invention, it has been discovered that the degree of optical absorbency is at least about the same as that of relatively free (unencapsulated) liquid crystal material, including pleochroic dye such as that shown in FIG. 1. It also has been discovered unexpectedly that when the electric field is applied in the manner illustrated in FIG. 6, for example, the clarity or lack of opaqueness of the encapsulated liquid crystal material 20 including pleochroic dye is at least about the same as that of the ordinary case in the prior art device 1 having dye in solution with relatively free liquid crystal material.

It is important that electrical field E shown in FIG. 6 is applied to the liquid crystal material 20 in the capsule 22 for the most part rather than being dissipated or dropped substantially in the encapsulating material of which the capsule itself is formed. In other words, it is important that there not be a substantial voltage drop across or through the material of which the wall 54 of the capsule 22 is formed; rather, the voltage drop should occur predominantly across the liquid crystal material 20 within the volume 21 of the capsule 22.

The electrical impedance of the encapsulating medium preferably should in effect be sufficiently larger than that of the liquid crystal material in the encapsulated liquid crystal 11 so that a short circuit will not occur exclusively through the wall 54, say from point A via only the wall to point B, bypassing the liquid crystal material. Therefore, for example, the effective impedance to induced or displacement current flow through or via the wall 54 from point A only via the wall 54 to point B should be greater than the impedance that would be encountered in a path from point A to point A' inside the interior wall surface 50, through the liquid crystal material 20 to point B' still within the volume 21, thence ultimately to point B again. This condition will ensure that there will be a potential difference between point A and point B, which should be large enough to produce an electric field across the liquid crystal material that will tend to align it. It will be appreciated that

due to geometrical considerations, namely the length through only the wall from point A to point B, for example, that such a condition can still be met even though the actual impedance of the wall material may be lower than that of the liquid crystal material contained therein.

The dielectric constants (coefficients) of the material of which the encapsulating medium is formed and of which the liquid crystal material is comprised and the effective capacitance values of the capsule wall 54, particularly in a radial direction, and of the liquid crystal material across which the electric field E is imposed should all be so related that the wall 54 of the capsule 22 does not substantially decrease the magnitude of the applied electric field E.

A schematic electric circuit diagram representing the circuit across which the electric field E of FIG. 6 is imposed is illustrated in FIG. 7. The electric field is derived from the voltage source 16 when the switch 17 is closed. A capacitor 70 represents the capacitance of the liquid crystal material 20 in the encapsulated liquid crystal 11 when such electric field is applied in the manner illustrated in FIG. 6. The capacitor 71 represents the capacitance of the wall 54 of the capsule 22 at an upper area (the direction conveniently referring to the drawing but having no other particular meaning) and is, accordingly, curved in a manner similar to that of the upper portion of the capsule 22 of FIGS. 5 and 6. The capacitor of the lower similarly represents the capacitance of the lower portion of the capsule exposed to the electric field E. The magnitudes of capacitance for each capacitor 70–72 will be a function of the dielectric constant (coefficient) of the material of which the respective capacitors are formed and of the spacing of the effective plates thereof. It is desirable that the voltage drop occurring across the respective capacitors 71, 72 will be less than the voltage drop across the capacitor 70; the result, then, is application of a maximum portion of the electric field E across the liquid crystal material 20 in the encapsulated liquid crystal 11 for achieving optimized operation, i.e., alignment, of the liquid crystal molecules thereof with a minimum total energy requirement of the voltage source 16. However, it is possible that the voltage drop in one or both capacitors 71, 72 will exceed the voltage drop across capacitor 70; this is operationally acceptable as long as the drop across the capacitor 70 (liquid crystal material) is great enough to produce an electric field that tends to align the liquid crystal material to and/or toward the field-on condition of FIG. 6, for example.

In connection with capacitor 71, for example, the dielectric material is that of which the wall 54 is formed relatively near the upper portion of the capsule 22. The effective plates of such capacitor 71 are the exterior and interior wall surfaces 73, 50, and the same is true for the capacitor 72 at the lower portion of the capsule 22 relative to the illustration of FIG. 6, for example. By making the wall 54 as thin as possible, while still providing adequate strength for containment of the liquid crystal material 20 in the volume 21, the magnitudes of capacitors 71, 72 can be maximized, especially in comparison to the rather thick or lengthy distance between the upper portion 74 of the liquid crystal material 20 of the lower portion 75 thereof which approximately or equivalently form the plates of the same number of the capacitors 70.

The liquid crystal material 20 will have a dielectric constant value that is anisotropic. It is preferable that the dielectric constant (coefficient) of the wall 54 be no lower than the lower dielectric (coefficient) of the anisotropic liquid crystal material 20 to help meet the above conditions. Since a typical lower dielectric constant for liquid crystal material is about 6. This indicates that the dielectric constant of the encapsulating material is preferably at least about 6. Such value can vary widely depending on the liquid crystal material used, being, for example, as low as about 3.5 and as high as about 8 in the commonly used liquid crystals.

The encapsulated liquid crystal 11 has features such that since the liquid crystal structure is distorted and since the pleochroic dye similarly is distorted, absorbency or blockage of light transmission through the encapsulated liquid crystals will be highly effective. On the other hand, due both to the efficient application of an electric field across the liquid crystal material 20 in the encapsulated liquid crystal 11 to align the liquid crystal molecules and the dye along therewith as well as the above described preferred index of refraction matching, i.e., of the encapsulating medium and of the liquid crystal material, so that incident light will not be refracted or bent at the interface between the capsule wall 54 and the liquid crystal material 20 when an electric field is applied, the encapsulated liquid crystal 11 will have a good optically transmissive characteristic.

Since a plurality of encapsulated liquid crystals 11 ordinarily is required to construct a final liquid crystal device, such as the device 10' of FIG. 3, and since those encapsulated liquid crystals are ordinarily present in several layers, it is desirable for the liquid crystal material to have a relatively high dielectric anisotropy in order to reduce the voltage requirements for the electric field E. More specifically, the differential between the dielectric constant (coefficient) for the liquid crystal material 20 when no electric field is applied which constant (coefficient) should be rather small, and the dielectric constant (coefficient) for the liquid crystal material when an electric field is applied, which constant (coefficient) should be relatively large, should be as large as possible consistent with the dielectric of the encapsulating medium.

The capsules 22 may be of various sizes. Also, when the capsule size is relatively small, more capsules are required per unit area of the layer 34, and, therefore, more electric voltage drop losses will occur in the encapsulating medium than for larger size capsules, the density per unit area of which would be smaller. Preferably, a device made with the encapsulated liquid crystals 11, such as the liquid crystal device 10', should use capsules of uniform size so that the device 10' can be energized or deenergized in a relatively uniform and well controlled manner. In contrast, when the capsules are of a non-uniform size, the non-uniform energization of the respective capsules, i.e., alignment of the liquid crystal molecules of each, would occur upon application of the electric field. Ordinarily the capsules 22 should have a size on the order of from about 1 to about 30 microns in diameter.

Currently a suitable liquid crystal material is smectic A phase material S2 sold by BDH Chemical, Pool, England. Another suitable liquid crystal material may be formed by mixing, in the proportions indicated in parenthesis, the following liquid crystals supplied by E. Merck Chemicals, Darmstadt, West Germany: K24 (18.7%), K30 (27%), K36 (40.8%), ZLI 1840 (6.5%), and CB15 (7%).

The encapsulating medium forming capsules 22 should be of a type that is substantially completely unaffected by and does not react with or otherwise chemically affect the liquid crystal material. In particular, the liquid crystal material should not be soluble in the encapsulating medium or vice versa. The other characteristics described above concerning dielectric constants (coefficients) and indices of refraction with respect to the liquid crystal material and to the encapsulating medium also constrain material selection. Moreover, when a pleochroic dye is employed, the encapsulating medium also should be unaffected by and should not affect the dye material. On the other hand, the dye should be soluble in the liquid crystal material and not subject to absorption by the encapsulating medium. Additionally, to achieve the desired relatively high impedance for the encapsulating medium, such medium should have a relatively high level of purity. Especially when the encapsulating medium is prepared as an aqueous dispersion or by ionic polymerization, etc., it is important that the level of ionic (conductive) impurities should be as low as possible.

lectrolytes. These media may be used alone or in combination with other polymers, such as PVA.

Other examples and characteristics of several PVA materials are shown in Table I.

An emulsion method for making encapsulated liquid crystals 11 may include mixing together the encapsulating medium, the liquid crystal material (including, if used, the pleochroic dye material), and perhaps a carrier medium, such as water. Mixing may occur in a variety of mixer devices, such as a blender, a colloid mill, which is most preferred, or the like. What occurs during such mixing is the formation of an emulsion of the ingredients, which subsequently can be dried eliminating the carrier medium, such as water, and satisfactorily curing the encapsulating medium, such as the PVA. Although the capsule 22 of each thusly made encapsulated liquid crystal 11 may not be a perfect sphere, each capsule will be substantially spherical in configuration because a sphere is the lowest free energy state of the individual droplets, globules or capsules of the emulsion, both when originally formed and after drying and/or curing has occurred.

TABLE I

CONTAINMENT MEDIUM (PVA)	VISCOSITY	% HYDROLYZED	MOLECULAR Wgt.	TEMPERATURE & % SOLUTIONS
20-30 Gelvatol, by Monsanto Company	4-6 CPS	88.7-85.5	10,000	4% at 20° C.
40-20 Gelvatol, by Monsanto Company	2.4-3 CPS	77-72.9	3,000	4% at 20° C.
523 Air Products and Chemicals, Inc.	21-25	87-89	—	4% at 20° C.
72-60 Elvanol, by DuPont Company	55-60	99-100	—	4% at 20° C.
405 Povel, by Kurashiki	2-4 CPS	80-82	—	4% at 20° C.

Examples of pleochroic dyes that may suitably be used in the encapsulated liquid crystals 11 in accordance with the present invention are indophenol blue, Sudan black B, Sudan 3, and Sudan 2, and D-37, D-43 and D-85 by E. Merck identified above.

Polyvinyl alcohol (PVA), which has been found to have the desired properties mentioned above, may be utilized as an encapsulating medium when the encapsulation is performed by emulsification. PVA has a good, relatively high, dielectric constant and has an index of refraction that is relatively closely matched to that of the preferred liquid crystal material.

To purify PVA, the same may be dissolved in water and washed out with alcohol using a precipitation technique. Other techniques also may be used for purifying PVA so that it will have minimum salt or other content that would reduce appreciably the electrical impedance thereof. A preferred purified PVA is Gelvatol sold by Mansanto. If PVA is properly purified, as aforesaid, it will serve well as its own emulsifier and as a wetting agent for facilitating the manufacture of encapsulated liquid crystals according to this method which will be described below. Other types of encapsulating medium may be, for example, gelatin; Carbopole; (a carboxy polymethylene polymer of B.F. Goodrich Chemical Corporation) Gantrez; (polymethyl vinyl ether/maleic anhydride) of GAF Corporation, preferably reached with water to form the acid, the latter two being polye-

Another encapsulating medium is latex. Latex may be a suspension of natural rubber or synthetic polymer or copolymer particles. A latex medium is formed by drying a suspension of such particles. A further explanation of the latex medium and methods of making the same are provided in U.S. Pat. No. 4,992,201, in the name of Pearlman, entitled LATEX ENTRAPPED NCAP LIQUID CRYSTAL COMPOSITION, METHOD AND APPARATUS, and which disclosure is hereby incorporated by reference.

Briefly, latex entrapped liquid crystal may be formed by mixing a suspension of latex particles and liquid crystal material wherein the liquid crystal material has been previously emulsified in an aqueous phase. Alternatively, all components may be combined prior to emulsifying the liquid crystal material. The mixture may then be applied to a substrate. As the mixture dries, it adheres to the substrate. When dried, the latex particles form a latex medium with particles of liquid crystal dispersed therein.

It is noted here that the characteristic of the pleochroic dye that it must be soluble in the liquid crystal material and that it not be subject to absorption by the water phase or polymer phase assures that such pleochroic dye will not be absorbed by the PVA, latex or other encapsulating medium or by the carrier medium, such as the water, used during the manufacturing process for the encapsulated liquid crystals 11.

EXAMPLE 1

A liquid crystal material having a smectic phase was formed by mixing the following liquid crystal materials, available from E. Merck Chemicals, Darmstadt, W. Germany:

K24	18.7%
K30	27.0%
K36	40.8%
ZLI 1840	6.5%
CB 15	7.0%

In order to insure good mixing, the components were dissolved in chloroform. The resulting temperature range was:

0° C. to 46° C.	smectic A
46° C. to 48° C.	cholesteric

The smetic liquid crystal (SLC) mixture was emulsified in a polymer solution which contained 92.5% PVA 20/30 (available from Airco, Allentown, Pa.) in an 80% water solution, 5% Gantrez 169 (89% water solution) and 2.5% glycerol.

The ratio of SLC mixture to PVA matrix was 1:2. The resulting emulsion was coated onto a Mylar film which had been previously evaporated with indium tin oxide (ITO). Use of a 2 mil-spaced doctor blade resulted in a dry film thickness of 0.5 mils.

The film was laminated to a second piece of ITO-coated Mylar, then placed in an oven at 100° C. for one hour. The result was a liquid crystal cell which was activated at 100 VDC, i.e., it became transparent. When the field was removed, the film remained transparent. Lesser voltages resulted in somewhat fewer degrees of alignment. In all cases, the liquid crystal emulsion remained in a state of activation. When the film was heated to 46° C. or above (heat-to-erase), its transition temperature, it returned to its original state, i.e., scattering.

EXAMPLE 2

Materials and procedure same as in Example 1, and further, M141, a 3% blue dye (available from Mitsui Toatsu Chemicals, Tokyo, Japan) was added to the above mixture, using chloroform as a solvent.

When the electric field was applied to the cell, the color changed from dark opaque blue to light transparent blue.

EXAMPLE 3

Same as Example 2, but a 3% yellow dye (G232 from Mitsui Toatsu Chemicals) was added. As a result, the cell changed from a dark opaque orange to a light transparent yellow when the electric field was applied.

EXAMPLE 4

A liquid crystal mixture was made which contained three parts K24 and one part CE3, both liquid crystals available from E. Merck. The resulting material was a smectic C at room temperature (24° C.), but became smectic A at 58°. The smectic A became cholesteric at 68.1°. At 76.6° the material became isotropic.

When an electric field of 60 V was applied to the resulting cell, it became transparent and the transparency remained until it was heated to about 76.6°.

In accordance with the present invention the quantities of ingredients for making the encapsulated liquid crystals 11, for example in the manner described above, may be, as follows:

The liquid crystal material—This material may be from about 5% to about 20% and preferably about 50% (and in some circumstances even greater depending on the nature of the encapsulating material) including the pleochroic dye of the total solution delivered to the mixing apparatus, such as a colloid mill. The actual amount of liquid crystal material used should ordinarily exceed the volume quantity of encapsulating medium, e.g., PVA to optimize the capsule size.

The PVA—The quantity of PVA in the solution should be on the order of from about 5% to about 50%, and possibly even greater depending on the hydrolysis and molecular weight of the PVA, and preferably, as described above, about 22%. For example, if the PVA has too large a molecular weight, the resulting material will be like glass, especially if too much PVA is used in the solution. On the other hand, if the molecular weight is too low, use of too little PVA will result in too low a viscosity of the material, and the resulting emulsion solidify adequately to the desired spherical encapsulated liquid crystals.

Carrier medium—The remainder of the solution would be water or other, preferably volatile, carrier medium, as described above, with which the emulsion can be made and the material laid down appropriately on a substrate, electrode or the like.

EXAMPLE 5

A method of making latex entrapped smectic liquid crystal may comprise adding 0.03 grams of the surfactant Igepol C0720 (available through GAF, N.Y., NY) and 0.03 grams of the surfactant DOW 5098 (available through Dow Chemical, Midland, Mich.) to 2.09 grams of S2 smectic liquid crystal material (available through BDH Chemical, Pool, England), and thereafter heating the composition to its isotropic temperature to dissolve it. The mixture may then be cooled to room temperature (24° C.) and 0.5 grams of $MeCl_2$ added to dissolve it. Then, 3.0 grams of Neorez R-967 (available through Polyvinyl Chemicals, Wilmington, Mass.) containing 40% of latex particles by weight may be added and mixed with an impeller blade at 2400 RPM for 3 minutes. Thereafter, 0.2 grams of a 5% solution of the cross-linking agent Tyzor LA (available through DuPont, Wilmington, Del.) is added with slow mixing at about 300 RPM.

The resulting temperature range was:

0° C. to 48° C.	smectic A
48° C. to 49° C.	nematic
above 49° C.	isotropic

With no field, incident light was scattered. The liquid crystal was in the nematic phase when heated to about 48° C., its transition temperature. An applied electric field permitted light to be transmitted through the liquid crystal. The liquid crystal was cooled to room temperature and the field was removed. Light was still transmitted through the liquid crystal. To cause scattering, the liquid crystal was again heated to its transition temperature of about 48° C.

EXAMPLE 6

Same as Example 5 but a 1% B1 blue dye (available through E. Merck) was added to the 32 liquid crystal material. As a result, when an electric field was applied, the color changed from opaque blue to light transparent blue.

It will be appreciated that since the uncured capsules or droplets of encapsulating medium and liquid crystal material are carried in a liquid, various conventional or other techniques may be employed to grade the capsules according to size so that the capsules can be reformed if of an undesirable size by feeding again through the mixing apparatus, for example, and so that the finally used capsules will be of a desired uniformity for the reasons expressed above.

Although an encapsulation technique has been described with reference to emulsification, since the fact that the encapsulant material and binder are the same makes facile the production of liquid crystal devices; the preparation of discrete capsules of the liquid crystal material may on occasion be advantageous, and the use of such discrete capsules (with a binder) is within the contemplated scope of this invention.

Although certain specific embodiments of the invention have been described herein in detail, the invention is not to be limited only to such embodiments, but rather only by the appended claims.

What is claimed is:

1. A liquid crystal apparatus, comprising:

a liquid crystal material having a smectic A phase and a non-smectic phase, the liquid crystal material in the smectic A phase exhibiting either a distorted alignment state or a light-transmissive state;

a containment means having discrete volumes for confining the liquid crystal material and said volumes having curved surfaces for inducing a generally distorted alignment of the liquid crystal material when the liquid crystal material is in the non-smectic phase and when no electric field is applied thereto, the distorted alignment at least one of scattering and absorbing light;

means for selectively applying an electric field across the liquid crystal material so the liquid crystal material is selectively switchable between the distorted alignment state where light is at least one of scattered and absorbed and the light transmissive state, the light transmissive state remaining after removal of the electrical field when the liquid crystal material is in the smectic A phase; and

means for applying heat to the liquid crystal material in the smectic A phase to put it in the non-smectic phase so the distorted alignment state can occur during a time in which no electric field is applied to the liquid crystal material.

2. The invention of claim 1, further comprising substrate means for supporting a layer of said liquid crystal material and said containment means.

3. The invention of claim 1, said liquid crystal material in the smectic A phase being optically anisotropic, and wherein the difference between the ordinary index of refraction of said liquid crystal material in the smectic A phase and the index of refraction of said containment means is no more than about 0.03.

4. The invention of claim 1, wherein said liquid crystal material in the smectic phase A has a positive dielectric anisotropy.

5. The invention of claim 1, said containment means comprising a solid medium forming individual capsules as said volumes.

6. The invention of claim 1, said containment means comprising a solid medium forming individual interconnected capsules as said volumes.

7. The invention of claim 1, said containment means comprising a dried stable emulsion.

8. The invention of claim 1, further comprising pleochroic dye mixed with said liquid crystal material.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,216,530

DATED : June 1, 1993

INVENTOR(S) : Kenneth N. Pearlman, et al

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

In Column 1, line 49, delete "know" and insert --known--.
In Column 4, line 6, delete "0.1" and insert --1--.
In Column 4, line 17, delete "as" and insert --are--.
In Column 4, line 23, delete "deviced" and insert --device--.
In Column 5, line 7, delete "Crystal" and insert --Crystals--.
In Column 13, line 61, delete "that".
In Column 17, line 59, delete "Mansanto" and insert --Monsanto--.
In Column 20, at the end of line 24, add --will not--.

Signed and Sealed this

Nineteenth Day of April, 1994

Attest:

BRUCE LEHMAN

Attesting Officer *Commissioner of Patents and Trademarks*

Job1643

19. Japan Patent Office (JP) 12. **Japan Laid-open Patent Gazette (A)** 11. Patent Application Laid-open No.
Showa 64-86116 (1989)
43. Patent Laid-open March 30, 1989 (Showa 64)

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54. Title of Invention: Electrophoretic Display Device

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Specification

1. Title of the Invention

Electrophoretic Display Device

2. Claims of Patent

(1) An electrophoretic display device wherein the space between a pair of opposing electrode plates at least one of which is transparent is filled with a disperse system containing electrophoretic particles, and the state of distribution of the electrophoretic particles in the disperse system is changed under the action of a display-

[1] ILS Note – An alternative way of reading this personal name is Shu.
[2] ILS Note - Despite an exhaustive search of available resources, we were unable to verify the Official company name. Phonetic translation is provided. Hereafter denoted as *.
[3] ILS Note – Alternative ways of reading this personal name are Akashi, Sho, and Teru.
[4] ILS Note – An alternative way of reading this personal name is Koshi.
[5] ILS Note – Alternative ways of reading this personal name are Takashi and Hisayuki.

controlling voltage applied across said electrodes in order to change the optical reflection properties and thereby to induce a specific display operation; in which are provided numerous microcapsules filled with a disperse system in which is dispersed, in a colored dispersion medium, at least one kind of electrophoretic particles the optical characteristics of which differ from those of said dispersion medium; with said device configured such that these microcapsules are arranged between the abovementioned electrode plates.

(2) An electrophoretic display device of Claim (1) of the present invention, wherein the volume resistivities of the abovementioned disperse system and microcapsules are for practical purposes the same.

3. Detailed Explanation of the Invention

(Field of Industrial Application)

The present invention concerns a display device utilizing electrophoretic particles; more precisely, it concerns an electrophoretic display device in which individual microcapsules are filled with a disperse system in which electrophoretic particles are dispersed in a dispersion medium, and these microcapsules are placed in the space between electrode plates.

(Prior Art and Problems Therewith)

In this type of electrophoretic display device using electrophoretic particles, the space between a pair of opposing electrode plates at least one of which is transparent is filled with a disperse system in which electrophoretic particles are dispersed in a liquid dispersion medium, and the electrophoretic particles in the dispersion medium are made to adhere to or be repelled from the transparent electrode plate side according to the polarity of said electrode plates, so that by controlling said polarity, any desired characters, symbols or figures can be displayed. As the liquid dispersion medium used in the disperse system, an alcohol solvent, various esters, aliphatichydrocarbons, alicyclic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, or various other hydrocarbons may be used either individually or in an appropriate mixture, with a surfactant added in an appropriate quantity. As the electrophoretic particles, carbon black, iron blue[6], phthalocyanine green, and other materials are known as general-use materials.

Figure 2 is a conceptual cross-sectional diagram of the main components of the electrophoretic display device in question. Here 1 and 2 are respectively glass sheets or some other transparent material, and transparent electrodes formed in the required pattern on one side; the space between this pair of transparent electrodes 2, placed to oppose each other, is filled with a disperse system 10 containing electrophoretic particles. In a construction in which the disperse system 10 simply fills the space between the electrodes, coagulation of the electrophoretic particles and adhesion phenomena may cause display unevenness; as methods of preventing such occurrences, constructions are known in which mesh-shaped spacers[7] 9 with numerous holes of an appropriate shape 9A as shown in Fig. 3, or perforated spacers 9 with numerous penetrating holes, are placed between the two electrodes 2, in order to divide the disperse system 10 into discontinuous areas and thereby stabilize the display operation.

In an electrophoretic display device provided with said perforated spacers 9, after placing said perforated spacers 9 between both transparent electrodes 2, each of the penetrating holes 9A formed in the perforated spacer 9 is filled with the disperse system 10; however, it is extremely difficult to uniformly fill the numerous penetrating holes 9A with the disperse system 10. One method which may be considered is to drip the disperse

[6] ILS Note – Alternative translations for this term are "Milori blue" and "navy blue."
[7] ILS Note – Although we have assumed that this term is plural, the Japanese text does not explicitly state whether multiple spacers are used.

system 10 onto or apply the disperse system 10 to each of the penetrating holes 9A after the perforated spacers 9 are formed on one of the transparent electrodes 2; but the dispersion media generally used in the disperse system 10 are easily vaporized, so that when using this method the characteristics of the disperse system 10 change and it is difficult to maintain reproducibility.

(Purpose of the Invention and Constitution)

Instead of using the above-described perforated spacers or similar parts, the present invention employs a method in which the disperse system is enclosed in microcapsules in advance. By this means an electrophoretic display device is offered in which the various above-described problems relating to the disperse system filling the space between transparent electrodes are satisfactorily eliminated, the process of inserting the disperse system is simplified, and good-quality electrophoretic display operation, including display of arbitrary colors, can be achieved reliably.

In order to attain this goal, in the electrophoretic display device of the present invention, the space between a pair of opposing electrode plates at least one of which is transparent is filled with a disperse system containing electrophoretic particles, and under the action of a voltage for display control which is applied across said electrodes, the distribution states of the electrophoretic particles within the dispersive system are changed, to alter the optical reflection properties and induce so-called display operation; and in this device are formed numerous microcapsules, which are filled with a dispersive system consisting of a colored dispersion medium in which are dispersed at least one type of electrophoretic particle with optical properties differing from said dispersion medium, with said microcapsules arranged between the abovementioned electrode plates. Here it is desirable that the volume resistivities of the abovementioned dispersive system and the microcapsule film are practically equal.

(Embodiment)

The present invention is explained in further detail below, referring to the embodiment shown in Fig. 1. In the figure, numerous microcapsules 3, each filled in advance by a microcapsule process with a disperse system 5 in which electrophoretic particles 4 are dispersed in a dispersion medium, are placed between the transparent electrodes 2 formed on the opposing surfaces of a pair of transparent sheets consisting of glass sheets or some other material. Here, the electrophoretic particles 4 of the disperse system 5 used to fill the microcapsules 3 may be, in addition to well-known colloidal particles, various other organic or inorganic pigments, dyes, metal powders, glass, resin or other fine powders, as appropriate. As the dispersion medium of the dispersive system 5, in addition to water, alcohols, hydrocarbons and halogenated hydrocarbons, various natural or synthesized hydrocarbons may also be used. To this dispersive system 5 may be added, as necessary, electrolytic materials, surfactants, metal soaps, resins, rubbers, hydrocarbons, varnish, compounds, and other charge-controlling agents consisting of particles, as well as dispersive agents, lubricants, stabilizing agents and other materials. Moreover, in addition to unifying the electric charge on the electrophoretic particles 4 undergoing electrophoresis at positive or negative charges and employing measures to raise the zeta potential or uniformly stabilize the dispersion, the adhesion to the transparent electrodes 2 of the electrophoretic particles 4 or the viscosity or other properties of the dispersion medium may be adjusted as appropriate.

The disperse system 5 with this composition is mixed thoroughly using a ball mill, sand mill, paint shaker or other appropriate means, and then a suitable method, such as interfacial polymerization, insolubilization reaction, phase separation, or interfacial precipitation, is used to enclose the disperse system 5 in microcapsules. Here, it is desirable that the volume resistivities of the film of the microcapsules 3 and the disperse system 5 be for practical purposes the same.

Microcapsules 3 obtained by this means are arranged on one of the transparent electrodes using a roller printing technique, a spray technique or some other method, and this may then be combined with the other transparent electrode 2 to fill the space between the two electrodes 2 with the microcapsules. In addition to the above means of filling the space between the electrodes 2 with the disperse system 5 using microcapsules 3, a method can also be employed in which appropriate filling holes linking the two electrodes are used to inject appropriate quantities of microcapsules 3.

In addition, for practical purposes it is desirable that the gaps between microcapsules 3 and the gaps between electrodes 2 and microcapsules 3 be filled via injection holes 6 with a material 7 which is chemically stable with respect to the microcapsules 3, and has for practical purposes the same refractive index and volume resistivity, as shown in Fig. 1. Here 8 denotes end sealing material.

(Effects of the Invention)

In an electrophoretic display device of the present invention, as has been described, the disperse system is encapsulated in microcapsules in advance, and these microcapsules are arranged in a plane between the electrodes used for display control. Consequently, there are at least the following advantageous results.

Because the composition of the disperse system in microcapsules is maintained to be uniform, coagulation of the electrophoretic particles or adhesion to the electrodes as in devices of the prior art are eliminated, and uniform and stable display operation is possible.

The device is constructed such that microcapsules are arranged between the electrodes used for display control, so that handling of the disperse system and processes for filling the space between the electrodes with the disperse system during assembly can be greatly improved without the need to consider adverse effects on the disperse system, to obtain an electrophoretic display device with satisfactory characteristics.

In encapsulating the disperse systems in microcapsules in advance, it is possible to produce disperse systems with various display colors, and appropriately arrange microcapsules with these different display colors to configure a desired color display; in doing so, no barrier walls or means of partitioning are needed.

4. Brief Explanation of the Drawings

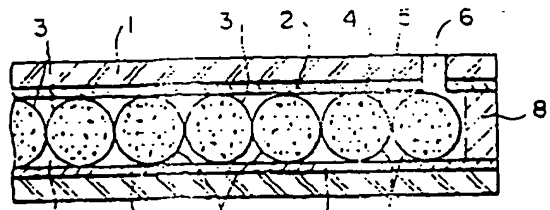
Figure 1 is a conceptual cross-sectional diagram of the main components of an electrophoretic display device provided with microcapsules filled with a disperse system, according to the Embodiment of the present invention;

Figure 2 is a conceptual cross-sectional diagram of the main components of an electrophoretic display device of the prior art, provided with perforated spacers; and,

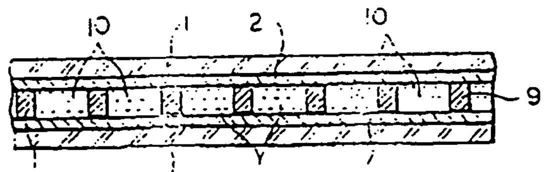
Figure 3 is a partial explanatory isometric diagram of an example of the construction of a perforated spacer.

1: Transparent material
2: Transparent electrode
3: Microcapsule
4: Electrophoretic particles
5: Disperse system
9: Perforated spacer
10: Disperse system

第 1 図



第 2 図



第 3 図